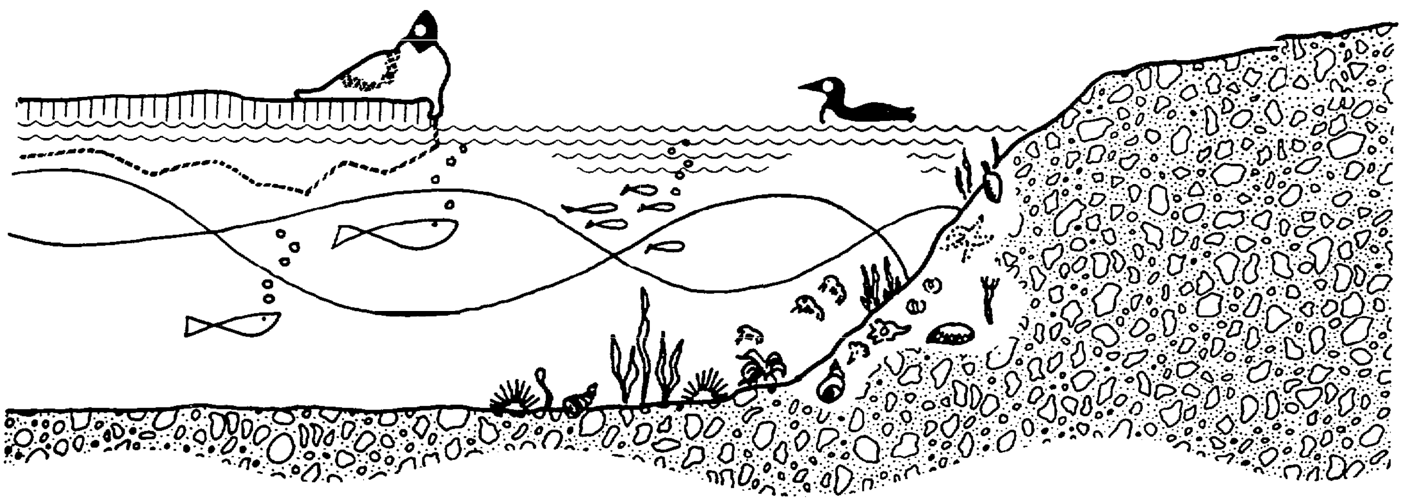
SHORELINE COUNTERMEASURES



Baffin Island Oil Spill Project

WORKING REPORT SERIES
$3-4

1983 STUDY RESULTS

BAFFIN IS LAND OIL S PILL PROJECT
WORKING REPORT SERIES

The Baffin Island Oil Spill (BIOS) Project is a multidisciplinary program of research on arctic marine oilspill fate, effects and countermeasures. The Project commenced in the spring of 1980 and has now completed the fourth and final year of planned field work at an experimental site located on the northern end of Baffin Island, Canada. The results of work performed in each of the various study components under the Project, have been made available on a yearly basis through this working report series. This has been done prior to a complete integration of findings and interpretation with respect to the Project objectives. The working report series should therefore be considered as interim or data reports. The contents do no necessarily reflect the views or policies of the BIOS Project management or funders.

For further information on the BIOS Project write the BIOS Project Manager, c/o Environmental Emergencies Technology Division, Environmental protection Service, Ottawa, Ontario, Canada K1A 1C8.

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Final Report

Baffin Island Oil Spill Project
1983 Shoreline Component

Prepared for

Environmental Protection Service
Environment Canada
Hull, Quebec

June 29, 1984

by

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1.0 INTRODUCTION

The Shoreline Component of the Baffin Island Oil Spill (BIOS) Experiment was designed to evaluate selected shoreline countermeasure techniques in the event of oil reaching arctic coasts. The programme was expanded subsequently to include studies of the oiled shorelines on the east coast of Ragged Channel following the nearshore experiments in that area. The programme commenced in 1980 with the establishment of a series of control plots that have been monitored in each open-water season over the four-year period of the study. A series of countermeasure experiments were conducted in 1981 and in 1982 in the vicinity of Z-Lagoon (Fig. 1.1). The location of the control plots and the experimental sites is presented in Figure 1.2 and a list of the individual experimental and control plots is presented in Table 1.1. Commencing in 1981 a series of investigations were carried out on Bays 9 and 11 in the Ragged Channel area (Fig. 1.2). These investigations focussed upon the fate and persistence of oil stranded in the shorezone from the spills in the adjacent nearshore waters.

The 1983 phase of the Shoreline Component of the BIOS Experiment involved a continuation of the previous years' studies. The primary objective of this phase was to resample and resurvey the oiled control and countermeasure plots and the beaches of Bays 9 and 11. The field sampling programme is described with additional detail and the total hydrocarbon analysis results are given by Humphrey (1984). Results of the geochemical analysis programme are given by Boehm (1984).

This report follows the same format as the 1982 Working Report (Owens et al., 1983), which should be consulted for further details on the countermeasure experimental procedures. The Working Report Series presents details of each previous phase of the study. The results of the 1983 field programme and of the subsequent sample analyses are discussed in this report in the context of the previous years' results. A summary listing of the plots and beaches that have been studied since 1980 is given in Table 1.1 and this table includes a listing of the activities conducted at each location as well as the codes used to designate each plot.

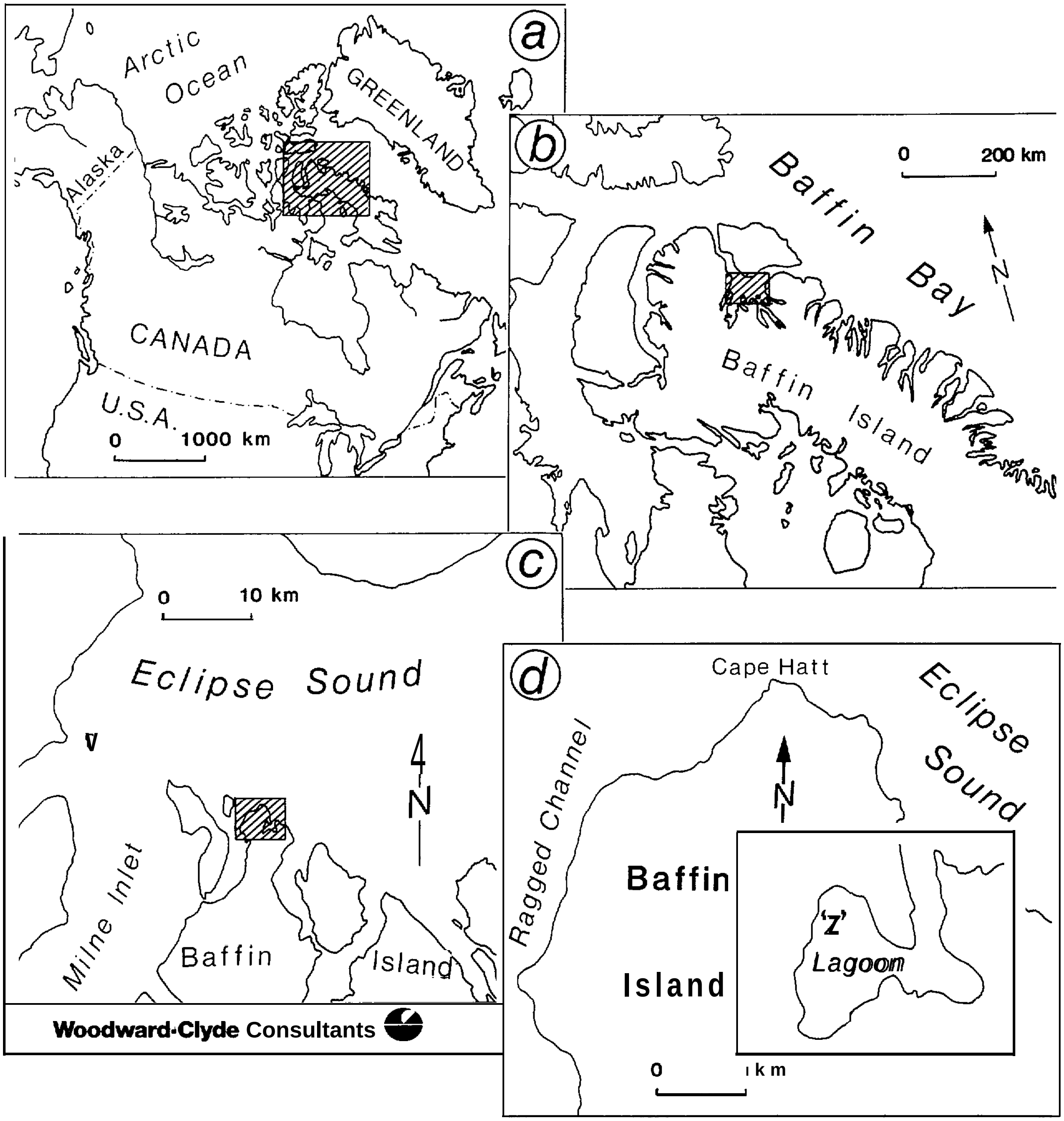


Figure 1.1 Regional location maps. The area within the rectangle in 'd' is shown in more detail in Figure 2.1 (page 2-2).

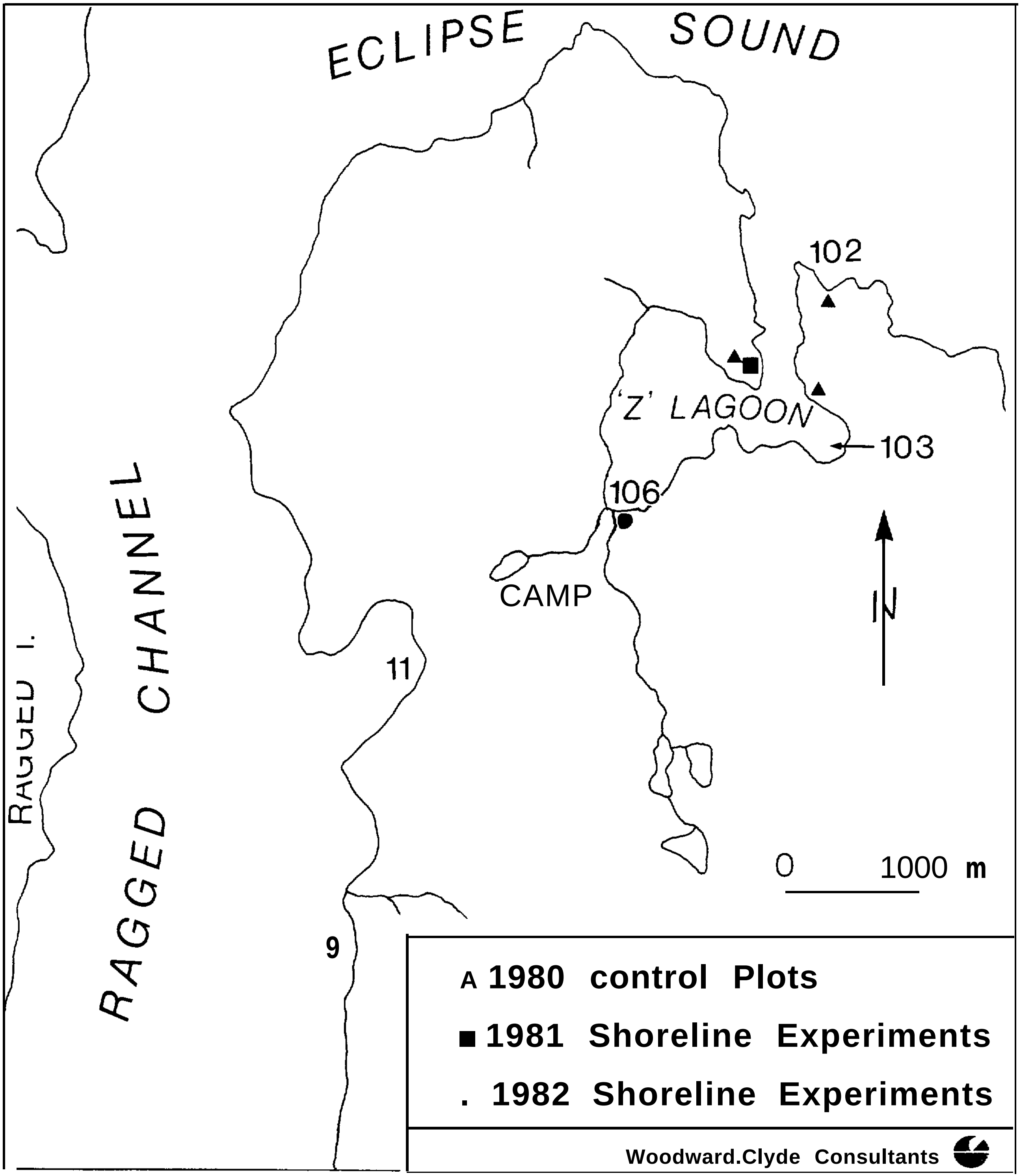


Figure 1.2 Location of the 'Z-Lagoon' study sites and of Bays 9 and 11 on the eastern shore of Ragged Channel (Latitude 72030': Longitude 79°50').

Table 1.1 Shoreline Component Experimental and Control Plots.

Site	Location	Year Oil Spilled	Plot Designation	Type of oil	Beach Zone	Activity
"H"	Bay 102	1980	H1 H2	crude emulsion	intertidal intertidal	control control
"L"	Bay 103	1980	L1 L2	crude emulsion	intertidal intertidal	control control
"C"	Crude Oil Point	1980	T1 T2	crude emulsion	backshore backshore	control control
"H"	Bay 102	1980	TE1 TE2	crude. emulsion	backshore backshore	control control
"C"	Crude Oil Point	1981	CC CE	crude emulsion	intertidal intertidal	control control
			D(B)C	crude	intertidal	dispersant (BP1100X)
			D(B)E	emulsion	intertidal	dispersant (BP1100X)
			D(E)C	crude	intertidal	dispersant Corexit 7664)
			D(E)E	emulsion	intertidal	dispersant Corexit 7664)
			MC ME	crude emulsion	intertidal intertidal	mixing mixing
			SC SE	crude emulsion	intertidal intertidal	solidified solidified
Ragged Channel	Bay 11	1981		crude	intertidal	control
"I"	Bay 106	1982	ICC ICE	crude emulsion	intertidal intertidal	control control
			ID(B)C	crude	intertidal	dispersant (BP1100X)
			ID(B)E	emulsion	intertidal	dispersant (BP1100X)
			ID(E)C	crude	intertidal	dispersant Corexit 7664)
			ID(E)E	emulsion	intertidal	dispersant Corexit 7664)
			IMC IME	crude emulsion	backshore backshore	mixing mixing

2.0 1980 CONTROL PLOTS

2.1 INTRODUCTION

Control plots were established in 1980 to enable comparisons to be made of weathering and the fate of oil between crude oil and emulsified oil at (1) a backshore site and (2) intertidal sites with different wave-energy levels. This data was also intended to be used in assessing the results of the countermeasure experiments.

As part of the 1983 field programme, sampling surveys were conducted on the 1980 intertidal and backshore control plots. The two backshore control plots at Crude Oil Point (T-1 and T-2) were resampled for total hydrocarbon content and for GC/MS analysis. The high-energy intertidal control plots (H-1 and H-2) and the low-energy intertidal control plots (L-1 and L-2) were sampled for total hydrocarbon and GC/MS analysis and were resurveyed along the topographic profiles established in 1980.

The two backshore control plots established in 1980 in Bay 102 (TE-1 and TE-2) were not surveyed during the 1983 field programme. These plots have been used primarily for the microbial degradation studies and are discussed elsewhere (Eimhjellen *et al.*, 1983).

2.2 1980 BACKSHORE PLOTS

2.2.1 Results Prior to 1983 Study

Two long-term backshore control plots were established above the high-water limit at Crude Oil Point during 1980 (Fig. 2.1). The controls were an aged crude oil plot (T-1) and a water-in-aged crude oil emulsion plot (T-2). One part of the eastern section of the T-1 plot was used by Eimhjellen *et al.* (1983) as part of a separate experiment.

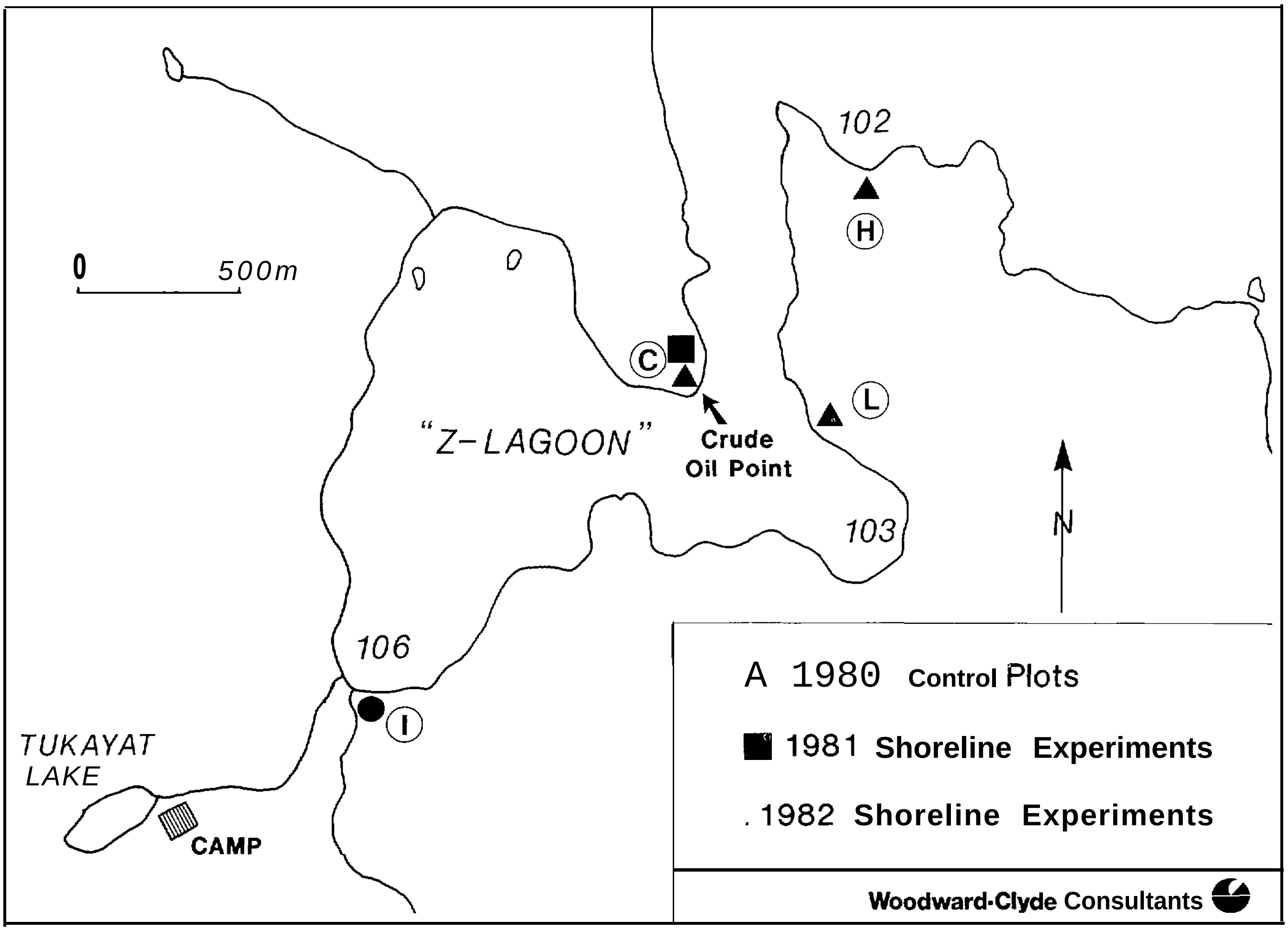


Figure 2.1 Experimental and control locations in the 'Z-Lagoon' area. The letters H, C, I and L refer to the sites described in Table 1.1.

The backshore control plots were set up to document the effects of atmospheric and microbial weathering (i.e. non-marine weathering) for comparison with the fate of the control plots that were established at the same time in the intertidal zone. The backshore plots were located on substrates similar to those of the adjacent active beaches. The oil loadings on the plots were at a rate of 1 cm^3 of oil per cm^2 of plot. Initial total hydrocarbon contents on the backshore control plots varied between 17,000 mg/kg and 54,000 mg/kg in the surface sediments. Differences in oil retention characteristics were apparent between the two oil types. More aged oil than emulsified oil was retained on the sediments. Initial mean total hydrocarbon contents of the aged oil plots as measured in 1980 ranged between 31,600 and 37,800 mg/kg, whereas the emulsified plots initially retained between 14,200 and 26,400 mg/kg.

Despite considerable scatter in the data the comparison of results between the 1980 and the 1981 surveys indicates that there was a small reduction in the total hydrocarbon content of the surface samples. Surface oil contents were apparently reduced more than the subsurface oil contents, and this trend was strongest for the emulsified oil plots. In 1981 there was therefore the suggestion that surface oil weathering was greater on emulsified oil plots than on the crude oil backshore plots. On the basis of saturated hydrocarbon weathering ratios (SHWR) and the Alkane/Isoprenoid (ALK/ISO) weathering ratios, a significant amount of weathering occurred between the last 1980 survey and the 1981 survey. On the basis of the 1981 survey it was apparent that a significant amount of oil still existed on all of the backshore control plots but that some evaporative weathering had taken place during that time.

The analysis of samples collected in 1982 on the backshore control plots shows that these results are within the range of values from the 1980 and the 1981 suite of samples. The diagnostic weathering ratios in 1982 show that evaporative weathering was significant prior to the 1981 sample set with little or no change between 1981 and 1982, and that biodegradation was not significant in the backshore plots in the 1982 sample set.

2.2.2 Results of 1983 Study

The two plots had undergone little visual change (Figs. 2.2 and 2.3: compare to Fig. 2.2 in Owens et al., 1983). The plots have a surface of hard oil, with some windblown sand but have not been effected by marine processes to date. Samples were collected in 1983 at four locations from the surface and subsurface of each of the two plots for subsequent analysis to determine the total hydrocarbon content of the sediments. In this study the hydrocarbon content is reported as weight of extracted hydrocarbon per total weight of sample (mg of oil/kg of sediment). Table 2.1 presents the results of the total hydrocarbon analysis for the period 1980 through 1983. The value for 1983 is the mean of four separate samples. The range of values for the surface samples on plot T-1 is 6,400 to 10,000 mg/kg, and for plot T-2 is 17,000 to 28,000 mg/kg (Humphrey, 1984). The range of values for the subsurface samples on plot T-1 is 6,700 to 13,000 mg/kg and on plot T-2 is 570 to 10,000 mg/kg.

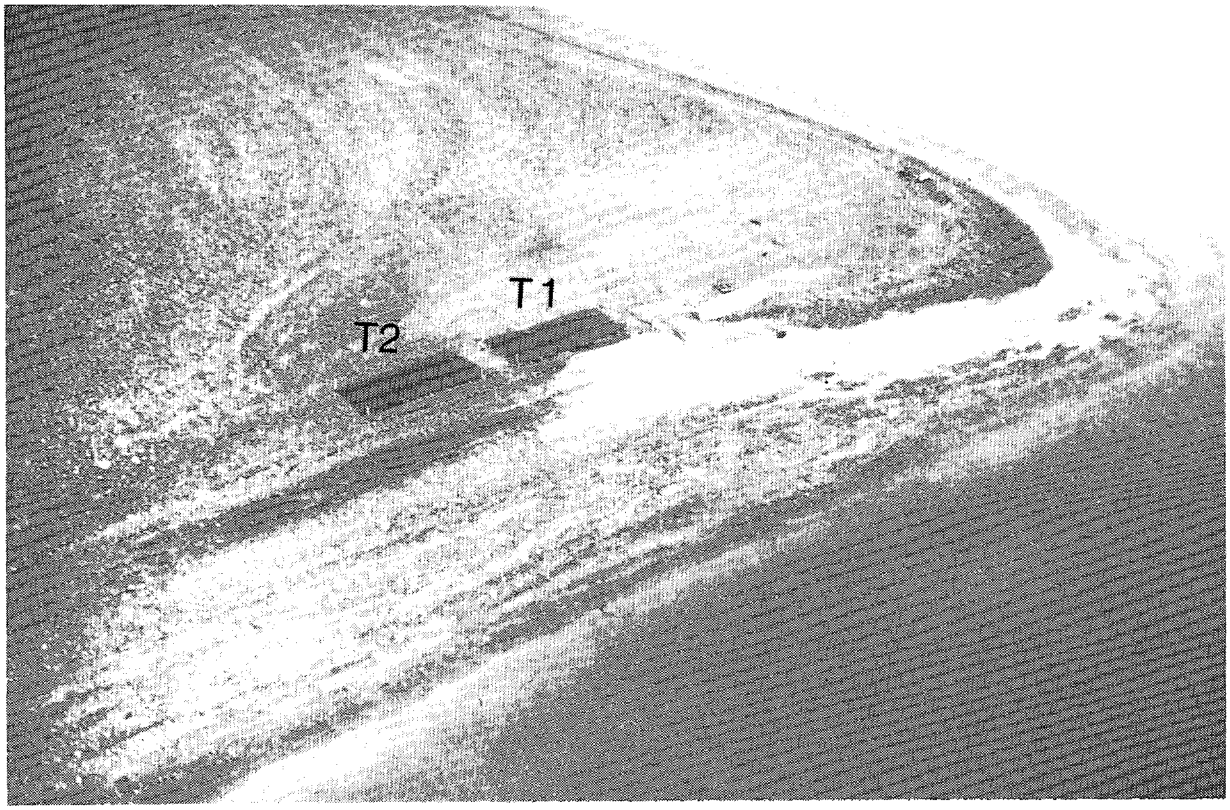


Figure 2.2 Aerial view of Backshore Control Plots at Crude Oil Point (12:10, 12th August, 1983).

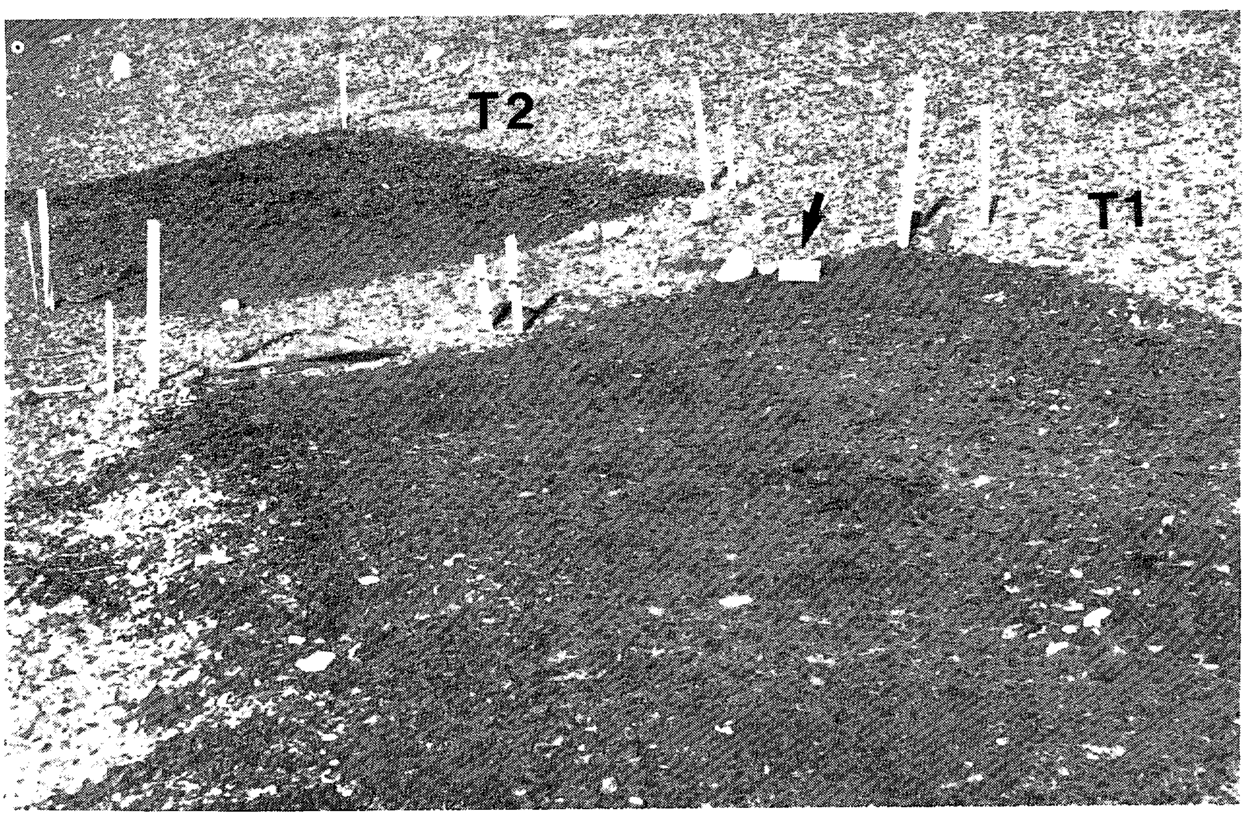


Figure 2.3 Close-up of Backshore Control Plots: Scale (shown by the arrow) in top corner of Plot T-1 is 25 cm in length (13th August, 1983) .

On plot T–1 there is a very significant difference between the values obtained from samples collected during 1982 and those obtained in 1983, from both the surface and subsurface. The highest of the four 1983 sample values is less than the values recorded in previous years. There exists no obvious explanation for this dramatic change in total hydrocarbon content. Previous results had indicated that the surface total hydrocarbon contents on plot T–1 had been stable since 1981, although there had been some reduction in the subsurface values. However, the change in the amount of oil remaining on the plot (Table 2.2) shows that a significant reduction had taken place in the values between the last sample collected in 1982 and the time of sampling in 1983. This is particularly intriguing because the visual observations in 1982 and 1983, as well as comparison of colour photographs, suggest that little or no change had taken place: the analytical results therefore were unexpected.

The total hydrocarbon content of the surface samples from the emulsion plot (T-2) show that little or no change had occurred between 1982 and 1983 (Tables 2.1 and 2.2).

The subsurface samples from this plot do however show a significant reduction in values; with the highest value of 10,000 mg/kg being lower than any of the previous values.

Samples were collected from both plots for geochemical analysis and the changes in the diagnostic ratios since 1980 are presented in Table 2.3. These results indicate that both the SHWR and the ALK/ISO ratio were lower on the crude oil plot (T-1) in 1983 when compared to previous results. By contrast no change in values from the surface of the emulsion plot (T-2) is evident in the data set for the Saturated Hydrocarbon Weathering Ratio and the Alkane/Isoprenoid ratio. These results suggest that on the crude oil plot there has been significant physical evaporative weathering and significant biodegradation of the surface oil between 1982 and 1983; but that these processes were not significant on the emulsion plot.

Table 2.1 Total Hydrocarbon Content of Backshore Control Plots (mg/kg).

		1980				1981		1982		1983
	DATE	20 Aug	22 Aug	24 Aug	28 Aug	28 July	29 Aug	10 Aug	2 Sept	20 Aug
T-1 (C)	surface	40,100	58,300	33,800	65,800	28,400	34,000	28,300	28,700	8,775
	subsurface	23,200	30,000	35,000	17,100	24,300	21,000	15,800	14,700	9,475
T-2 (E)	surface	13,100	19,700	12,700	60,000	14,400	16,000	16,700	17,800	22,500
	subsurface	15,400	27,100	13,300	58,100	20,600	18,000	16,800	13,500	5,917

C: CRUDE OIL
E: EMULSION

2.3 1980 INTERTIDAL CONTROL PLOTS

2.3.1 Results Prior to 1983 Study

On the intertidal control plots an application of 0.4 m^2 (90 Imperial Gallons) per test plot provided an approximate thickness of 1 cm of crude oil or 2 cm of emulsified oil. However, due to surface run-off during and immediately after the application, considerably less than these values were retained on the plots. On most plots the oil retention was within 80 per cent of the design amount, but on the low-energy plots oil retention was poor due to a high groundwater table.

On the exposed beach (plots H-1 and H-2 in Bay 102) mechanical wave action was effective in dispersing the oil. Within 48 hours between 50 to 90 per cent of the spilled oil was removed from the plots as a result of wave action on the beach. At the sheltered location (plots L-1 and L-2 in Bay 103) tidal action removed between 30 and 90 per cent of the spilled oil within the initial eight-day period following application. Wave action is not a significant factor at this latter site so that the primary processes by which oil was removed were related to water-level changes alone. Removal of oil was found to be most significant on the plots which were characterised by a high groundwater table. The initial set of results in 1980

Table 2.2 Amount of Initial Oil Remaining on Backshore Control Plots (%).

	DATE	1980 20 Aug	1980 22 Aug	1980 24 Aug	1980 28 Aug	1981 28 July	1981 29 Aug	1982 10 Aug	1982 2 Sept	1983 20 Aug
T-1 (C)	surface	100%	145	84	164	71	85	71	72	22
	subsurface	10C%	129	151	74	105	91	68	63	41
T-2 (E)	surface	100%	150	97	453	110	122	127	136	172
	subsurface	100%	176	86	377	134	117	109	88	38

C: CRUDE OIL
E: EMULSION

Table 2.3(a) Saturated Hydrocarbon Weathering Ratio (SHWR) Values on Backshore Control Plots (surface).

	1980 (INITIAL)	1980 (8 DAYS)	1981	1982	1983
T-1 (CRUDE)	2.4	2.2	1.6	1.6	1.1
T-2 (EMULSION)	1.9	.8	1.6	1.3	1.4

(b) Alkane/Isoprenoid Ratio (ALK/ISO) Values on Backshore Control Plots (surface).

	1980	1980	1981	1982	1983
T-1 (CRUDE)	2.4	3.0	2.1	2.4	1.9
T-2 (EMULSION)	2.6	2.3	2.4	2.4	2.2

indicated that local variations in beach characteristics and in beach morphology are partially responsible for the observed results. A lower oil retention on the low-energy emulsified plot (L-2) than that which occurred on the low-energy aged crude oil plot (L-1) was due primarily to a finer sediment size and to a higher groundwater table on the L–2 plot. Erosion of the beach surface of the emulsified oil high-energy plot (H-2) occurred during a period of high wave activity, whereas at the same time sediments were deposited on the aged oil plot (H-2) which resulted in partial burial of that oil.

Comparison of results between late August 1980, late July 1981 and late August 1981, show that between the first two periods the quantities of oil that remained on the Bay 102 plots were very similar but that by the third date all of the samples collected from the high-energy plots showed no traces of oil (Table 2.4). On these exposed intertidal control plots, wave action was therefore effective in causing the redistribution of sediments and the natural cleaning of the oiled test plots within one year. On the more sheltered plots in Bay 103, comparison of the sample data collected in 1981 showed that by August of that year 5 to 10 per cent by weight of the original oil remained on the surface of the plots and that 10 to 30 per cent remained in the subsurface of the sediments. A difference between the crude oil plot and the emulsion plot was observed visually and was indicated also by this sample analysis that showed lower total hydrocarbon values on the emulsified plot.

In **1982** at the low-energy control site in Bay 103 the crude oil plots showed a 50 to 70 per cent covering of oil in the upper part of the plot with less than 20 per cent in the lower part of the L–1 plot. By comparison the emulsion plot (L-2) showed almost no visible oil on the surface. Results to the total hydrocarbon analysis indicated that relatively high concentrations of oil, approximately 5,000 mg/kg, persisted on the crude oil plot but that virtually no oil was present on the emulsion plot. Similarly, subsurface oil concentrations on L-1 were comparable to the surface concentrations whereas no oil was present in the subsurface sediments of the emulsified plot.

Table 2.4 Amount of Initial Oil Remaining on Intertidal Control Plots (%).

		1980				1981		1982		1983
		INITIAL	+2 DAYS	+4 DAYS	+8 DAYS	BEGIN YEAR 2	END YEAR 2	BEGIN YEAR 3	END YEAR 3	MID YEAR 4
H-1 (C)	surface	100%	<1	<1	3	<1	0	0	0	0
	subsurface	100%	27	55	81	4	0	0	0	0
H-2 (E)	surface	100%	<1	<1	<1	9	0	0	0	0
	subsurface	100%	<1	<1	<1	2	0	0	0	0
L-1 (C)	surface	100%	30	23	38	27	10	18	28	4
	subsurface	100%	34	47	90	32	31	61	55	55
L-2 (E)	surface	100%	7	5	4	1	4	2	<1	<1
	subsurface	100%	6	1	6	6	14	0	0	0

The results over the period 1980 to 1982 indicate that on the L-1 plot the oil concentrations in the subsurface were reduced less than those of the surface samples over that time period. The trend also shows that most of the reduction in the volume of oil on the L-2 plot occurred within two days of the initial oiling in 1980 and that subsequent changes have been small, even though virtually all the oil had been removed by the end of 1982.

Results from the geochemical analyses indicated that evaporative weathering (SHWR) was significant between the first and the second years (1980 and 1981) but that such changes were subsequently small between 1981 and 1982, with similar trends occurring on both the crude oil and the emulsified oil plot. The ALK/ISO Ratio, an indicator of microbial degradation, indicated that biological weathering of the oil had occurred on both plots, but to a slightly greater extent on the emulsion plots. The changes occurred primarily between the first and second years (1980 and 1981) with only a small change between 1981 and 1982.

2.3.2 High-Energy Intertidal Control Plots (H-1 and H-2) - 1983 Results

A composite sample was collected from each of these two plots to determine if any oil was present in the surface or subsurface sediments. The results of the analysis for total hydrocarbon content indicate that no oil was present in the samples (Table 2.4). Some oil was visible at the high-water mark above the plots on the east end of Bay 102. A sample collected at this site provided a value of 1,300 mg/kg. This patch of oil was small, approximately 20 cm wide and 1 m in length, and consisted of stained granule and pebble sediments. These oiled sediments could have been deposited following erosion of either of the two intertidal control plots or of the backshore control plots that were set up as part of the Norwegian experiment in the western end of Bay 102 (see Section 2.4 in Owens et al., 1983). The Saturated Hydrocarbon Weathering Ratio and the Alkane/Isoprenoid ratio for the sample from the oil patch were respectively 1.20 and 0.77.

These high-energy intertidal control plots have been essentially oil-free since the middle of the 1981 open water season (Table 2.4). The oil patch at the high-water mark had been observed in previous years and is the only visual indication that this beach had been oiled.

2.3.3 Low-Energy Intertidal Control Plots (L-1 and L-2) - 1983 Results

Surface and subsurface samples collected on each of the two plots were a composite of 3 alongshore (i.e. parallel to the waterline) sub-samples.

Oil was still visible in the upper part of the crude oil plot (L-1) in 1983 (Figures 2.4 and 2.5). However, the amount of oil remaining on the surface, in comparison to previous years, was considerably reduced (Table 2.4). This reduction in the amount of oil remaining on the surface of the crude oil plot (L-1) is evident from the total hydrocarbon data (Table 2.5) which shows that the oil reduction was particularly significant on the surface in the middle section of the plot. At the time of the sampling in 1983 it had become evident that the middle and lower sections of the plot had been largely cleaned by wave processes. In both the surface and sub-surface sediments the majority of the oil remaining on the plot was con-

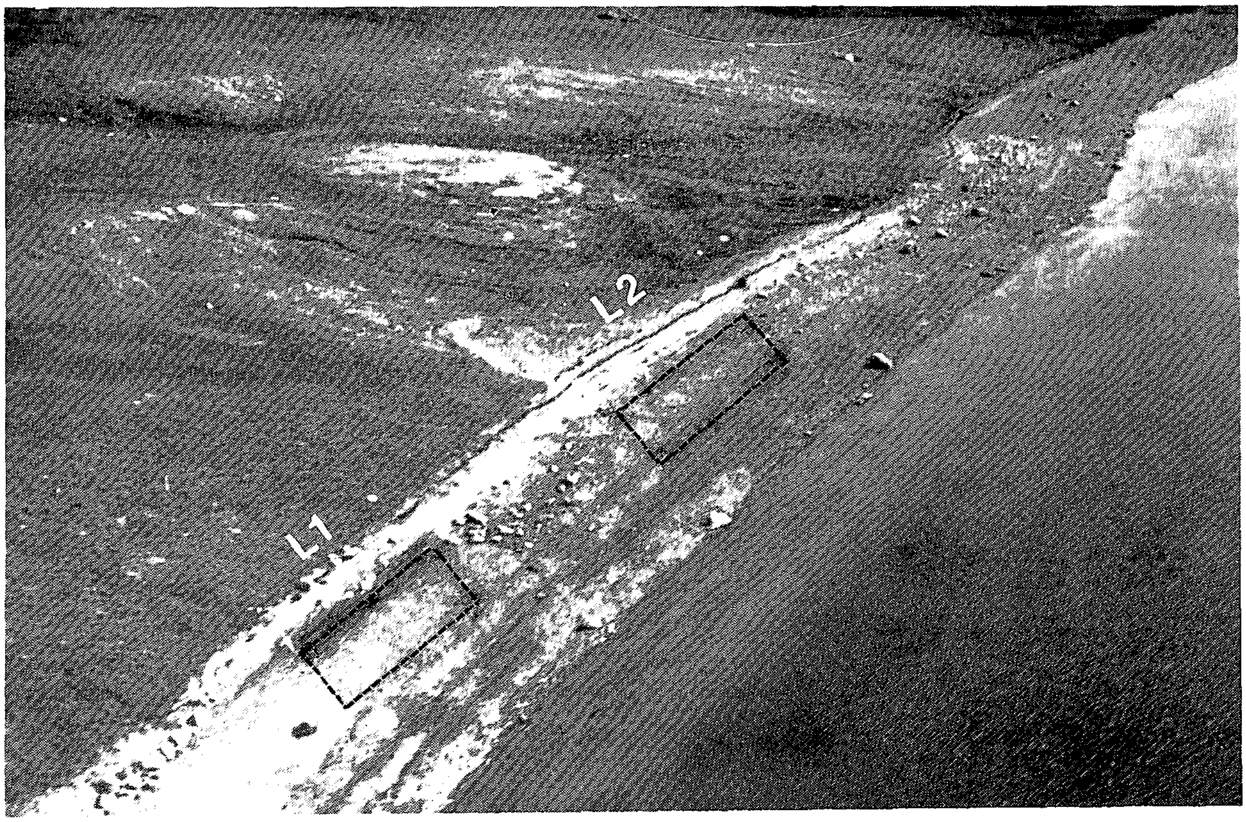
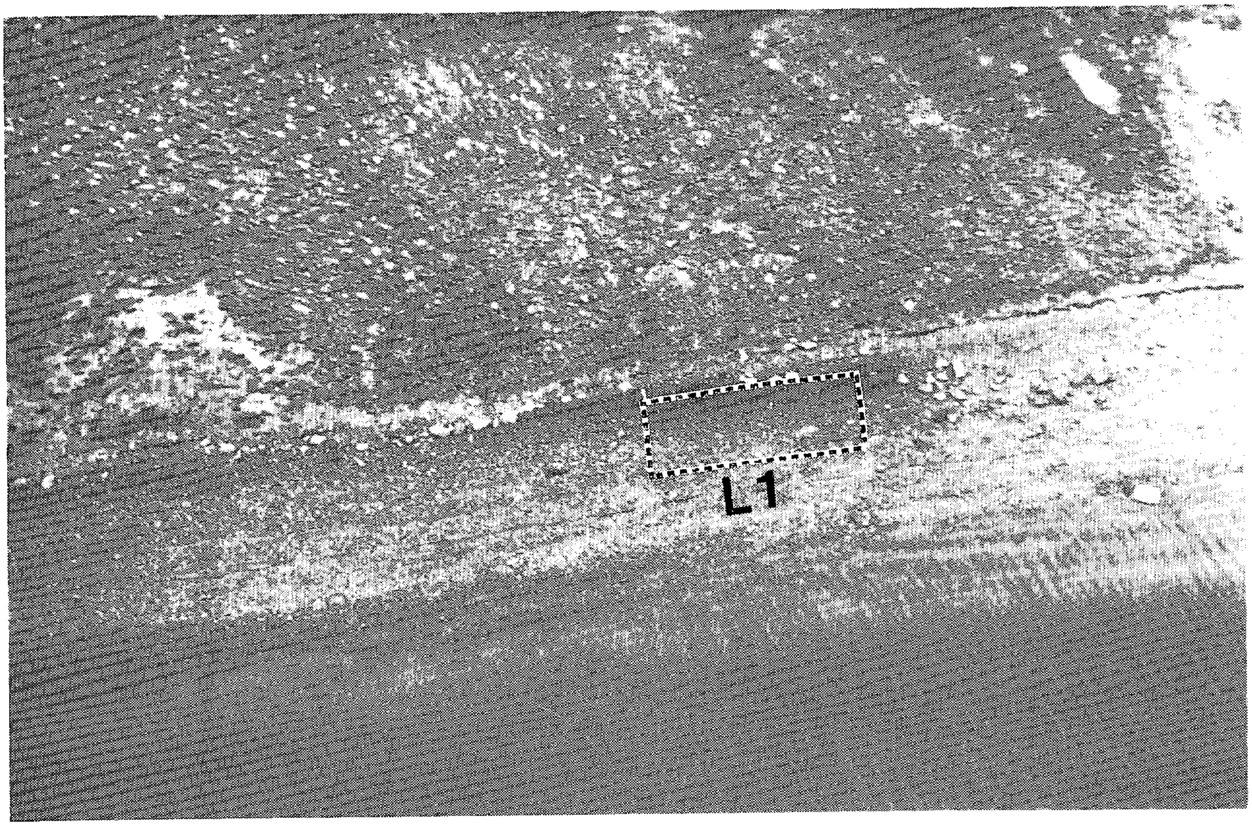


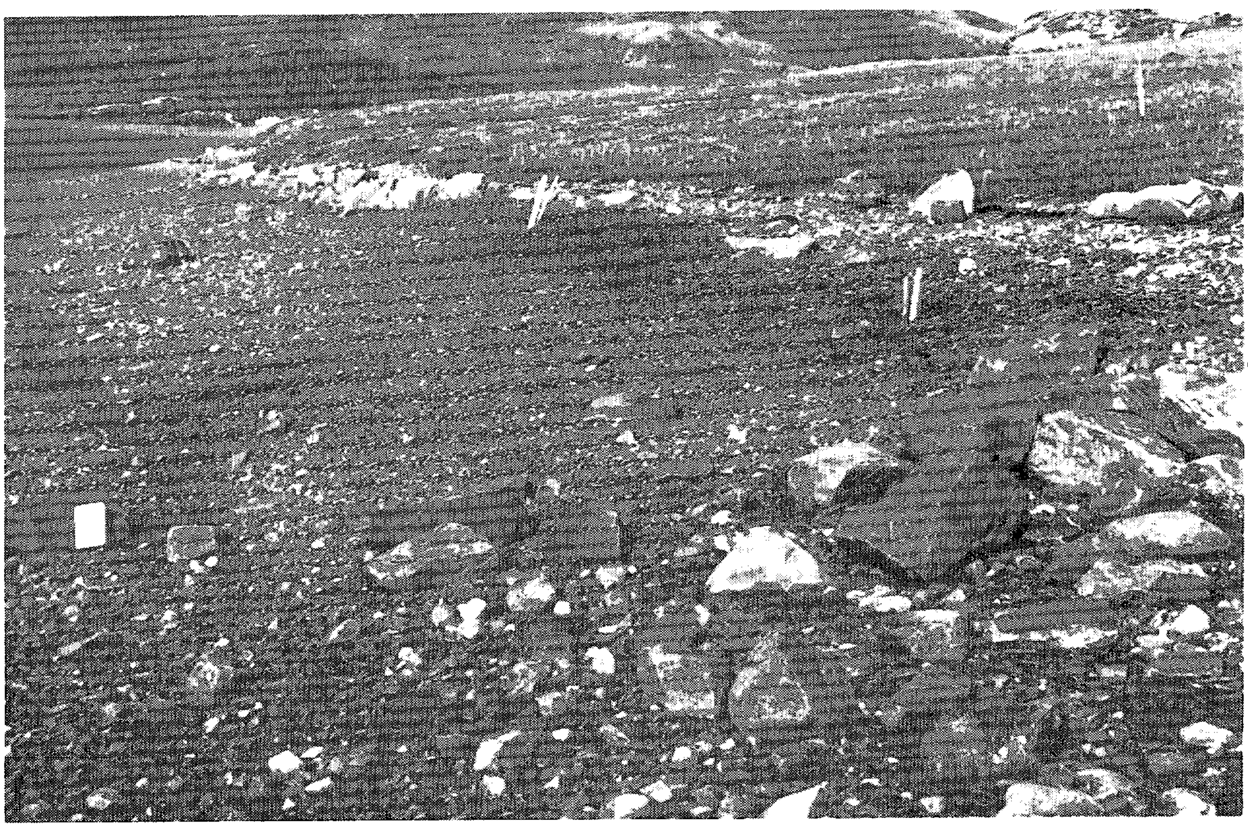
Figure 2.4 Aerial view of low-energy intertidal control plots (12:35, 14th August, 1983).

centrated parallel to the high-water line in the upper section of the plot (Figure 2.5). This is the zone of least wave activity. A considerable amount of oil remains in the subsurface sediments in the upper part of the plot (Table 2.5).

An additional surface and subsurface sample was collected just above the crude oil plot (L-l), at the high-water line. These two samples were composite from three alongshore subsamples. Analysis of the samples produced values of 1,500 mg/kg for the surface sample and 1,100 mg/kg for the subsurface sample. These values are in the same range as the surface composite sample on the upper part of the crude oil plot. Some transportation of the oil sediments has taken place since the oil was laid down and this has resulted in the redistribution of contaminated sediments over a relatively small area immediately adjacent to the upper part of the plot (Fig. 2.5).



(a)



(b)

Figure 2.5 (a) Aerial view of L-1 (12:10, 12th August, 1983).
(b) Close-up of plot L-1: the two pairs of stakes mark the top corners of the plot (14th August, 1983).

Table 2.5 Total Sediment Hydrocarbon Content (mg/kg), low-energy Intertidal Control Plots (L-1 and L-2).

PLOT L-1 AGED CRUDE, LOW ENERGY

		1980				1981		1982		1983
	DATE	21 Aug	23 Aug	25 Aug	29 Aug	28 July	29 Aug	10 Aug	2 Sept	20 Aug
UPPER	surface	6,700	4,600	4,500	5,700	4,790	2,520	2,150	2,580	1,200
	subsurface	8,800	8,000	7,700	12,600	5,770	5,390	15,700	8,480	23,000
MIDDLE	surface	8,700	11,700	2,500	7,700	2,920	1,090	1,750	11,500	280
	subsurface	13,000	900	9,400	18,300	7,470	4,690	9,830	13,200	1,900
LOW	surface	36,000	6,100	4,700	6,000	6,460	1,290	5,540	440	400
	subsurface	24,600	6,900	4,700	10,800	1,820	4,510	3,030	3,840	730
PLOT L-2 EMULSION, LOW ENERGY										
UPPER	surface	1,300	210	80	370	70	170	0	0	20
	subsurface	500	110	20	20	tr	190	0	0	0
MIDDLE	surface	4,500	320	340	10	290	170	0	40	0
	subsurface	2,200	60	10	160	130	160	0	0	0
LOW	surface	3,700	140	40	10	50	100	230	0	0
	subsurface		50	10	50	70	130	0	0	0

On the emulsion plot (L-2), very little oil remained in 1982. The results of the sample analyses from 1983 indicate that this situation has not changed and that essentially this beach had been cleaned naturally by the littoral processes (Tables 2.4 and 2.5: Fig. 2.6).

Samples were collected for geochemical analysis from both the surface and subsurface of the L-1 and L-2 plots. On the crude oil plot (L-1) a sample was obtained from the upper, or 'oiled', section of the plot and also from the lower, 'clean', section of this plot. In Table 2.6 the two 1983 values from the L-1 plot are both presented: the first value being from the upper section of the plot and the second value from the lower section of the plot.

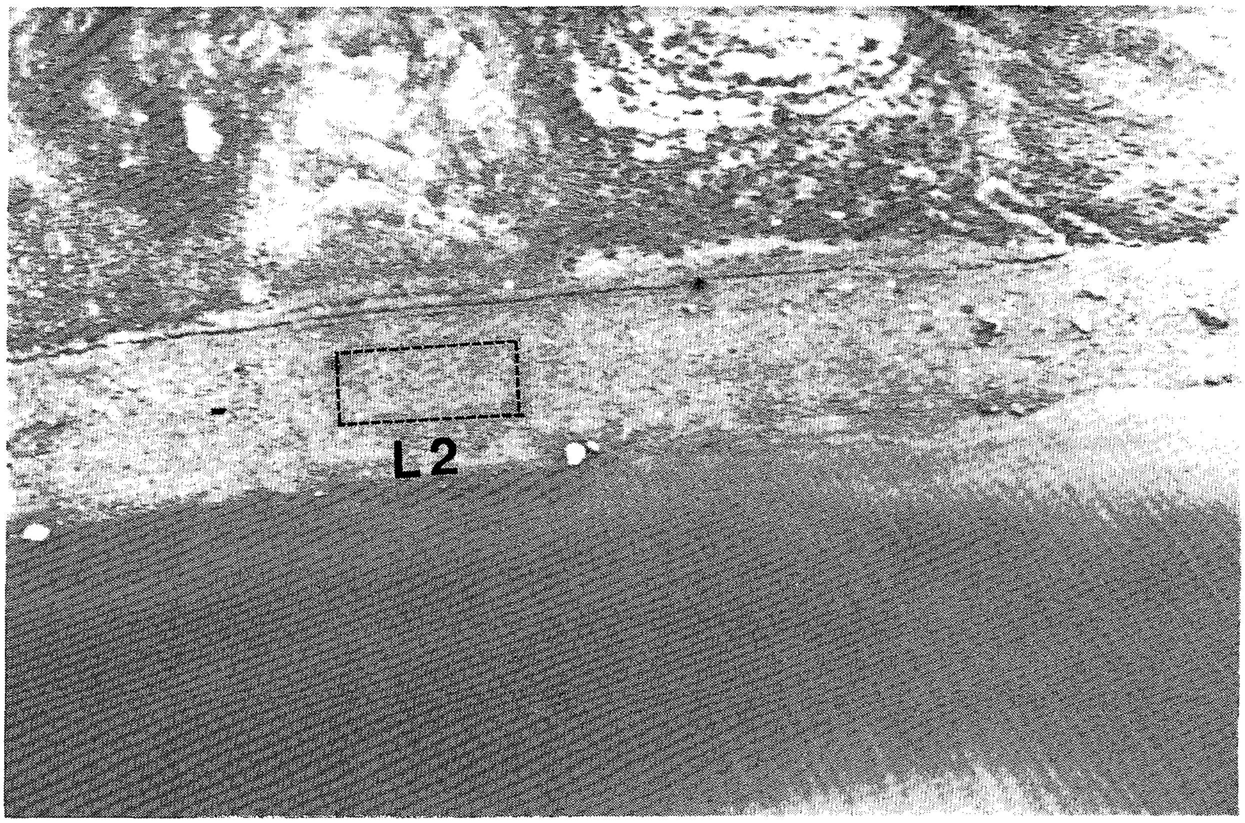


Figure 2.6 Aerial view of plot L-2 (12:10, 12th August, 1983).

Saturated Hydrocarbon Weathering Ratios from samples collected on the low-energy intertidal plots (Table 2.6a) indicate low values, similar to those that had been recorded since 1981. The two values from the crude oil plot (L-1) are virtually identical, indicating that the same physical evaporative weathering processes had taken place across the surface of this plot. Additional samples collected from the subsurface on both low-energy plots produced values of 2.0 and 1.2 for plot L-1 (on the upper and lower sections respectively) and a value of 1.4 for plot L-2. This suggests that the evaporative weathering rates in the central and lower subsurface sections of the plots were the same order as those on the surface of the plots, but that on the upper section of L-1 there was little reworking of the subsurface sediments by littoral processes so that the buried oil remained relatively unaffected by physical weathering processes.

Table 2.6(a) Saturated Hydrocarbon Weathering Ratio (SHWR) Values on the Intertidal Control Plots.

		1980 (INITIAL)	1980 (8 DAYS)	1981	1982	1983
H-1	(C)	1.3	1.8	2.0	1.8	
H-2	(E)	1.0	1.2	2.1	1.7	
L-1	(C)	2.5	2.5	1.1	1.3	1.1/1.0
L-2	(E)	2.1	2.0	1.0	1.1	1.3

(b) Alkane/Isoprenoid Ratio (ALK/ISO) Values on the Intertidal Control Plots.

		1980 (INITIAL)	1980 (8 DAYS)	1981	1982	1983
H-1	(C)	2.6	2.8	1.6	1.4	
H-2	(E)	3.0	2.4	2.4	1.4	
L-1	(C)	2.4	2.5	1.9	1.7	0.9/1.7
L-2	(E)	2.7	2.8	1.1	1.1	1.7

C: CRUDE OIL
E: EMULSION

Alkane/Isoprenoid Ratios (Table 2.6b) from the crude oil plot (L-1) show a marked difference between the upper ('oiled') and lower ('clean') sections of this plot. Microbial degradation of the oil appears to have been more rapid since 1982 on the section of the plot that contains more oil, whereas in the lower, cleaner, sections of this plot the rate of biological degradation appears to have been slower and at a rate similar to that on the emulsion plot (which was also relatively oil-free). Alkane/Isoprenoid ratios from subsurface samples collected on the two plots were 2.1 and 1.0 respectively for the upper and lower sections on L-1 and 1.1 for the subsurface on L-2. These results indicate a reverse situation to that interpreted for the surface sediments, with higher rates of degradation on the cleaner areas and a lower rate of degradation on the more oiled upper section of L-1.

2.4 SUMMARY

Observations and sampling of the control plots have been conducted since 1980. The significant points that arise from the 1983 field observations and sample analyses are:

- although there was no visual change to the backshore control plots (T-1:T-2), which remained unaffected by marine processes, there occurred a significant reduction in the surface and subsurface total hydrocarbon values on the crude plot (T-1) between the 1982 and 1983 sample periods; a similar large reduction in total hydrocarbon contents occurred in the subsurface sediments of the emulsion plot (T-2)

- there is no evident explanation for the large change in total hydrocarbon values on backshore control plots

- no oil was present on the high-energy intertidal control plots (H-1:H-2), as in previous years: a small patch of oil at the high-water level produced a total hydrocarbon value of 1300 mg/kg

- the oil content of the low-energy intertidal crude oil plot (L-1) continued to be reduced as a result of wave activity in this sheltered environment; the amount of oil remaining in the middle section of the plot was considerably reduced, although oil remains in the upper section of the plot and at the high-water level above the plot; the emulsion plot (L-2) remained oil-free

- on the intertidal plots the trends that were recorded in 1980 through to 1982 continue into 1983; the most significant element recorded in 1983 is the large reduction in the total hydrocarbon values on the backshore control plots, particularly on the crude plot (T-1) - to which there is no obvious explanation at this stage

- the initial loadings of aged crude oil ranged between 6,000 and 46,000 mg/kg with a median in the order of 25,000 to 35,000 mg/kg. These values are in the same range as real-world spill situations so that the results can be generally applied. The backshore plots are valuable examples of oil stranded above the limit of normal activity and the intertidal plots have provided very useful data on rates of natural dispersal.

3.0 1981 COUNTERMEASURES EXPERIMENTS

3.1 INTRODUCTION

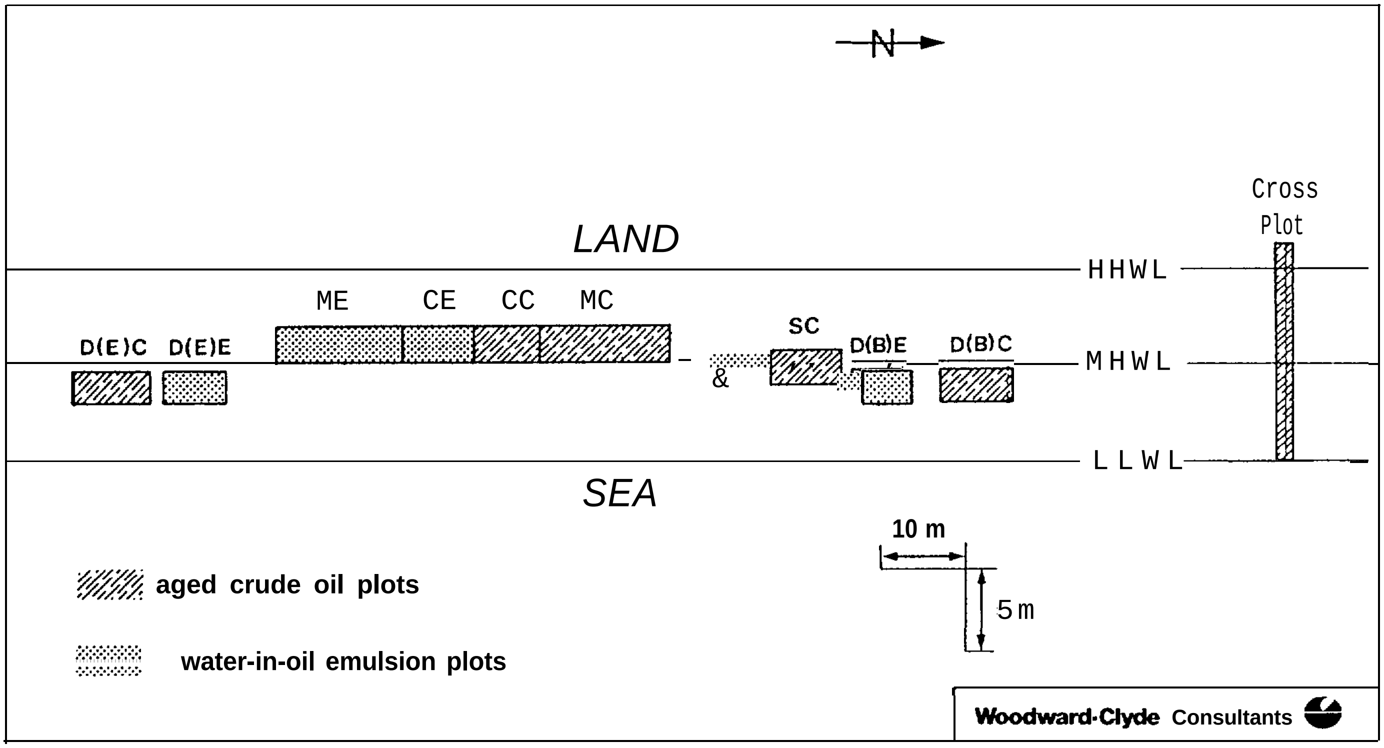
The purpose of the countermeasure experiments was to evaluate selected techniques for the cleanup of oiled arctic shoreline environments. Each countermeasure was evaluated in terms of the potential applicability of the technique and the effectiveness in terms of the persistence of stranded oil. The focus of the evaluation was a comparison with intertidal control plots laid down at the same time as the experiments, rather than a comparison of one technique or one dispersant to another. All of the selected countermeasures were tested on both aged crude and water-in-oil emulsion plots.

Experiments were carried out on a series of intertidal plots (Fig. 3.1) on an east facing beach at the entrance to Z–Lagoon. The site is referred to in this investigation as Crude Oil Point (see Fig. 2.1, page 2-2).

The techniques that were selected for the detailed experiments were as follows:

- a hydrocarbon based dispersant (BP 1100X) that was applied with a hand sprayer and backpack (plots D(B)C and D(B)E)
- a dispersant (Corexit 7664) that is designed for use with a relatively high velocity system, in this case a fire hose, to provide mixing energy (plots D(E)C and D(E)E)
- mechanical mixing, using a rototiller, to simulate the action of heavy equipment in the intertidal zone (plots MC and ME)
- a solidified agent that was applied to the plots to encapsulate the stranded oil; the agent consisted of a polymer and a cross linking agent (Plots SC and SE)

The two control plots were designated CC and CE for the crude and emulsion plots respectively.



.gure 3.1 Layout of 1981 countermeasures experiment and control plots at Crude Oil Point. The location of the plots is shown on Figure 1.2, and plot identification codes are given in Table 1.1.

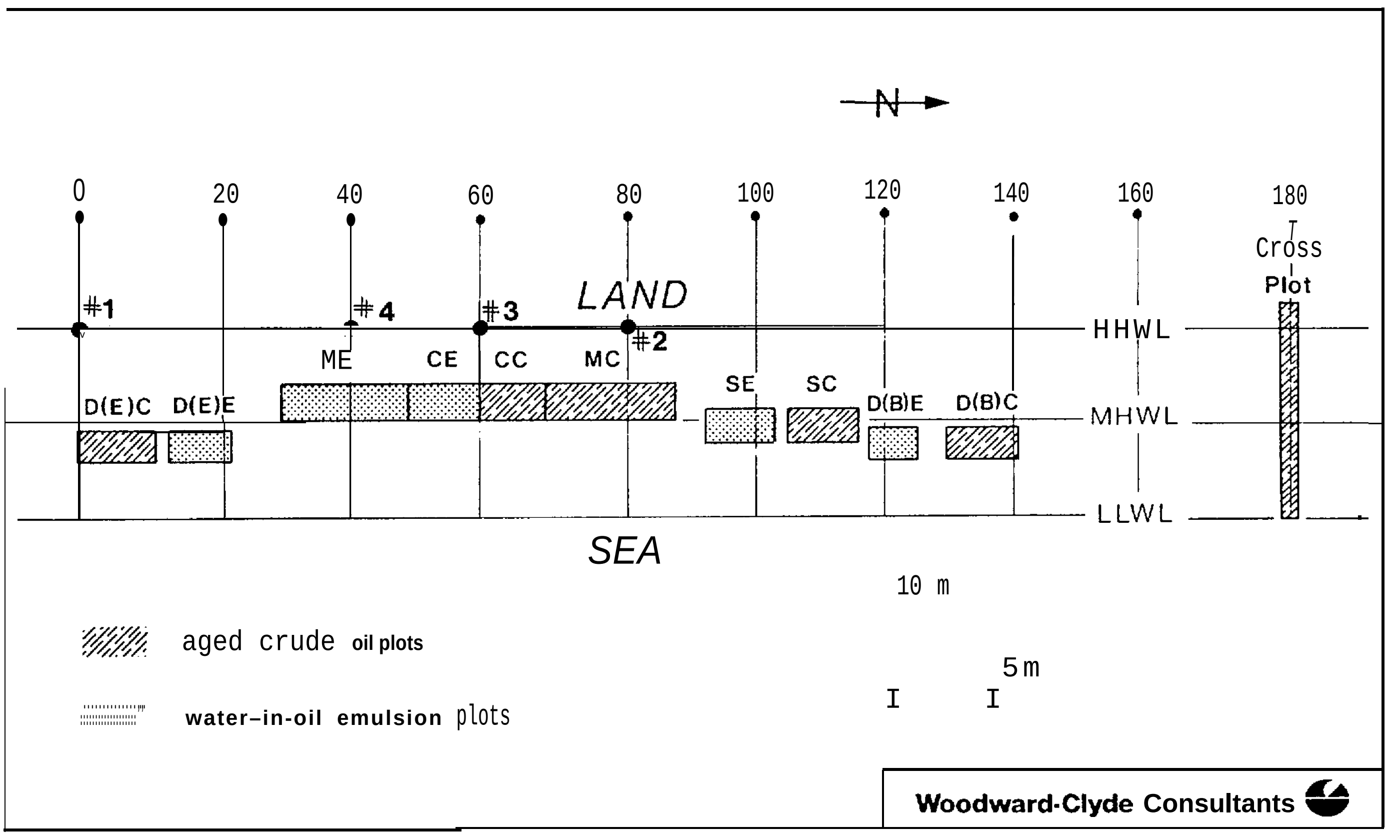


Figure 3.2 Location of beach profiles with reference to the countermeasures experimental plots. The numbered dots refer to sample locations noted in the text.

The primary activity of the 1983 field component was to resample the countermeasure plots to determine hydrocarbon levels in the sediments after three open-water seasons. The initial experimental design is fully documented in Owens et al., (1982). The results of the 1981 and 1982 field activities are reported by Owens et al., (1983) and summarised below in Section 3.2.

Samples for total hydrocarbon analysis were collected in 1983 from each of the experimental and control plots, with the exception of the two solidified plots (SC and SE in Fig. 3.1). Surface and subsurface samples were collected as a composite of three subsamples from the plot. Additional surface and subsurface samples were collected at four locations where oil was observed above the plots in the vicinity of the highest high-water mark. These samples were collected along the survey profile lines as indicated in Figure 3.2. One surface and one subsurface sample were collected from each of the two control plots (CC and CE) for detailed geochemical analysis.

3.2 RESULTS PRIOR TO 1983 STUDY

On the control plots which were established in the intertidal zone (CC and CE in Fig. 3.1) the initial loading was up to 20,000 mg/kg of oil in sediment by weight. Within forty days of application of the oil to the plots over 80 per cent of that oil has been dispersed naturally. The countermeasure techniques that were tested were evaluated in relation to these control plots. Techniques that were tested initially included:

- in-situ combustion using an incendiary device
- mechanical mixing of contaminated sediments
- chemical surfactants to disperse the oil
- application of solidifying agent to the oil surface

Preliminary tests indicated that the incendiary device did not ignite the oiled sediments and this technique was not included in the final experiment. On the plots that were subject to mechanical mixing there was an initial reduction in the surface concentration of oil-in-sediments with an increase in the subsurface concentrations of oil. However, within forty days following the experiment the values from the two mixing plots were in the same range as those from the two control plots. The application of different commercially available brands of dispersant resulted, immediately following the tests, in a significant reduction of both surface and sub-surface oil-in–sediment concentrations. Total hydrocarbon analysis results indicate that the dispersants reduced the oil-in-sediment volume by approximately one order of magnitude. Again, after forty days, the total hydrocarbon values from the dispersant parts were in the same range as those from the control plots. The application of the solidifying agent to the plots was successful in terms of the objective as the oil was effectively encapsulated within the gel.

The most significant result from the experiments and studies conducted in 1981 was that the levels of contamination after forty days were similar on the control plots to the countermeasure plots. The techniques that were tested, with the exception of the gel, could significantly reduce oil loadings during the period immediately following stranding of the oil at the shoreline. On the basis of the results, it appears in the long run that these techniques are no more efficient than natural degradation in terms of reducing the volume of oil that remains in the intertidal zone in this type of shoreline environment.

Resurveys and resampling of the control and countermeasure plots in 1982 indicated that relatively little oil remained on any of the plots. By September, 1982, only the mixed crude oil plot had a total hydrocarbon value greater than 500 mg/kg. Some oil remained in the vicinity of the mean high-water mark following redistribution of contaminated sediments by normal wave processes, but it is significant that no such band of oil sediments was present above the dispersant or solidified plots. The 1981 results also show that more oil remained on the control and mixing plots than on the majority of the dispersant plots and that with one exception (CE) subsurface total hydrocarbon values were greater than the surface values. The solidified oil was still present on the plots in 1982, and the surface cover was approximately 25 per cent. After two open-water seasons, it was concluded that the use of dispersants had resulted in lower total hydrocarbon values on both initial (one week) and long term (two open-water seasons) intervals but that the mixing technique appeared to have delayed natural cleaning to some degree.

3.3 TOTAL HYDROCARBON ANALYSIS 1983 RESULTS

3.3.1 Surface Samples

The results of the total hydrocarbon analysis on the surface sediment samples show a range of values from O to a maximum of 32 mg/kg (Table 3.1). These values are considerably lower than those which were recorded in the second sample period of 1982 and indicate that natural processes during the open-water interval between the two sample collections had further cleaned the control and countermeasure plots. In Table 3.2 the results are expressed in terms of the per cent of oil remaining with respect to the initial oil volume. This data set indicates that all of the plots have less than 0.2 per cen't oil remaining.

Oil was observed at the highest high-water mark above the plot locations, in the vicinity of profiles O through 80 (Fig. 3.2: Fig. 3.3: and Fig 3.4). In the aerial photograph (Fig. 3.3) the oil appears as a dark stain in the area indicated by the arrow. On the ground the oil is visible as a band of stained sediments in the vicinity of the highest high-water mark. In the ground photograph (Fig. 3.4) the two dark bands are lines of seaweed. The oiled sediments are above these bands on the berm crest, which is indicated by the double arrow. Analysis of the four surface samples produced values of 80, 680, 1200, and 440 mg/kg for sample Nos. 1, 4, 3 and 2 respectively. These values are considerably higher than the results from the intertidal plots themselves. The oiled sediments in the vicinity of the high-water mark were redistributed by wave processes that cleaned the countermeasure and control plots after the 1981 experiments. The process of redistributing the contaminated sediments further up the beach resulted in the deposition of this material in an area of minimal wave activity. Wave action is only possible at this elevation during periods of spring tides or during periods of storm-generated high-water levels during the restricted openwater season. The rate of natural cleaning of this contaminated line of sediments is therefore slower than for sediments lower down the beach in the intertidal zone.

Table 3.1 Results of Total Extractable Hydrocarbon Analyses - 1981 Countermeasures Control and Experimental Plots (mg/kg).

CODE		1981 Pre-Test	1981 Post-Test	1981 +8 Days Aug 15	1981 +40/31 Days Sept 16	1982 Aug 10	1982 Sept 02	1983 Aug 20
CC	surface	21,000	*	17,000	3,110	3C0	80	22
	subsurface	3,020	*	1,500	150	3,380	220	430
CE	surface	12,000	*	21,700	930	90	500	21
	subsurface	1,060	*	380	110	390	300	190
MC	surface	21,000	28,000	4,980	19,000	160	140	32
	subsurface	3,020	10,000	16,000	1,800	1,240	2,280	3,2C0
ME	surface	12,000	21,000	19,000	1,890	230	100	20
	subsurface	1,060	290	310	190	1,070	450	84
D(E)C	surface	25,000	6,070	440	360	80	90	20
	subsurface	300	5,940	2,390	170	900	50	20
D(E)E	surface	24,000	20,000	2,370	330	130	370	0
	subsurface	150	513	290	tr	170	260	120
D(B)C	surface	4,310	10,000	tr	tr	0	0	0
	subsurface	*	3,130	3,190	tr	30	0	0
D(B)E	surface	7,370	2,740	70	tr	0	0	0
	subsurface	70	4,400	80	tr	0	0	0

* No sample

Table 3.2 Per cent of Oil Remaining through Time from Initial Oiling - Surface Samples (a plus sign indicates an increase in volume).

CODE	1981 Pre-Test	1981 +8 Days	1981 +40/41 Days	1982 Aug 10	1982 Sept 02	1983 Aug 20
CC	10C%	81	15	1.4	0.4	0.1
CE	100	+181	8	0.8	5	0.2
MC	100	24	81	0.8	0.7	0.15
ME	100	+158	16	1.9	0.8	0.15
D(E)C	100	1.8	1.4	0.3	0.4	0.1
D(E)E	100	10	1.4	0.5	1.5	0
D(B)C	100	0	0	0	0	0
D(B)E	100	0-9	0	0	0	0

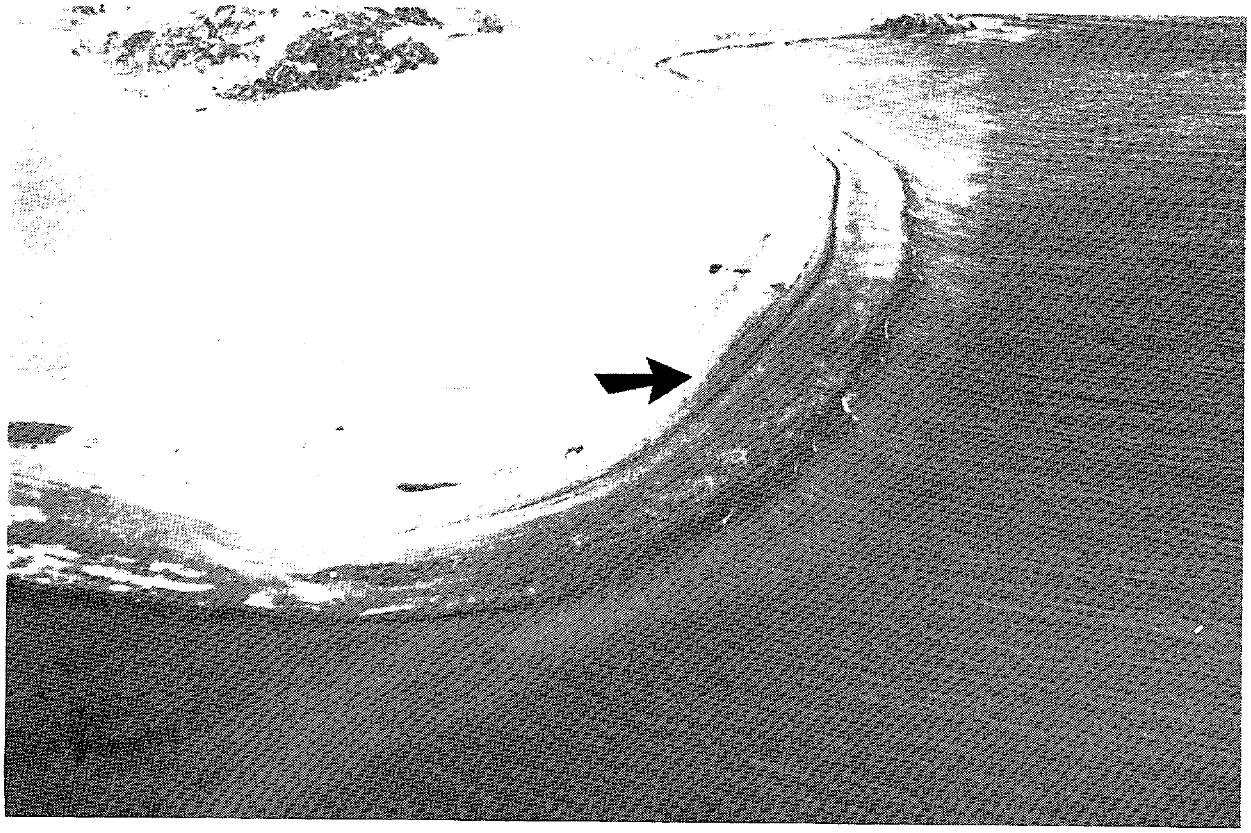


Figure 3.3 Aerial view of Crude Oil Point (12:30, 14th August, 1983). The arrow locates Figure 3.4.

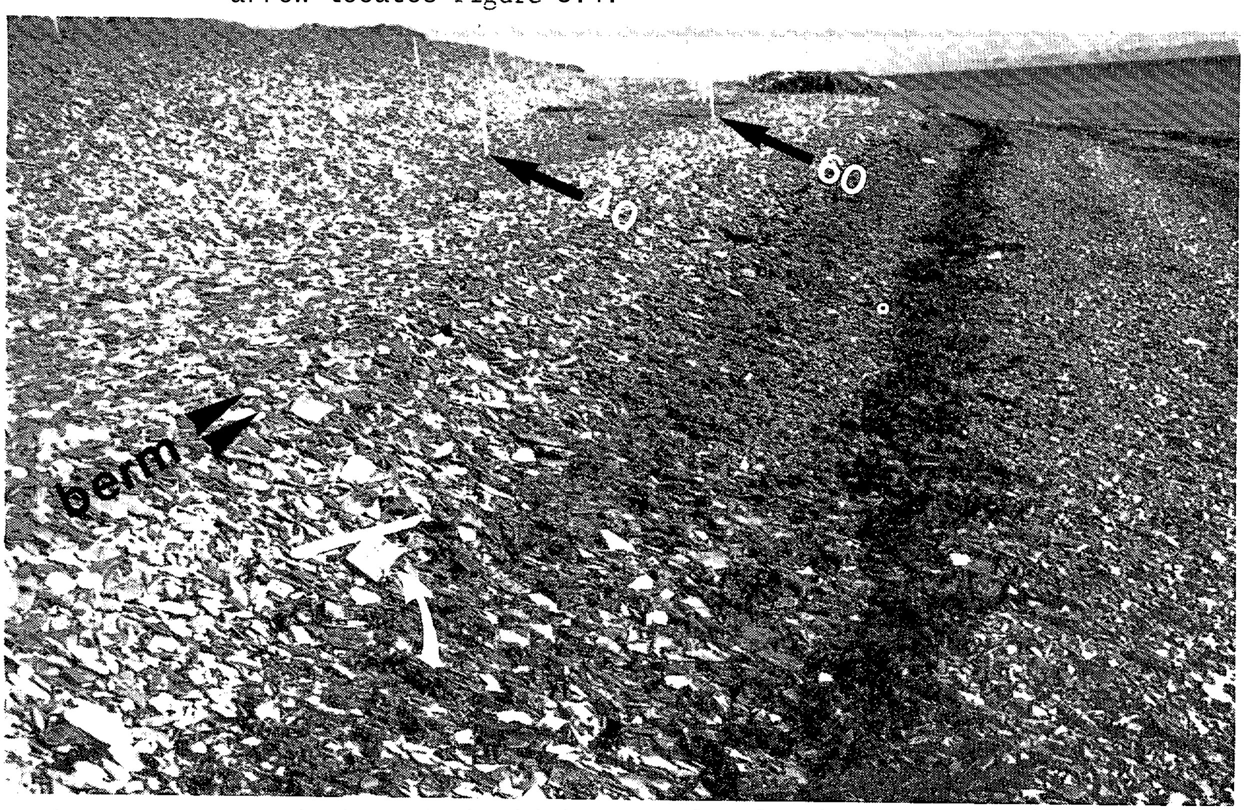


Figure 3.4 Ground view of the high-water level taken from Profile 20: arrows with numbers indicate stakes on Profiles 40 and 60. The scale indicated by the single white arrow is 25 cm in length. The double arrow defines the berm crest (13th August, 1983).

Observations at Crude Oil Point showed that between profiles 80 and 100 (Fig. 3.2) remnants of the solidified oil from plots SC and SE were present at the high-water mark (Fig. 3.5). It is of interest to note that several of these large pieces of solidified beach had undergone little or no apparent change since 1981.

At the southern end of Crude Oil Point, oil was still present in the vicinity of the test plots which had been oiled in 1981. Figure 3.6 compares to Figure 3.5 in Owens et al., 1983 and illustrates that the oil in this relatively sheltered section of shoreline had altered little since August, 1982.

"3.3.2 Subsurface Samples

The range of values from the 1983 subsurface samples is O to 3,200 mg/kg. This range and the individual sample results (Table 3.1) indicate little change from the second 1982 sample set. The volume of oil retained in the subsurface of the MC plot remains high. Also, no oil was found to be present in either of the DB plots, which have had consistently low values since 15th August, 1981.

The results of the subsurface sample analysis, expressed in terms of the per cent of oil remaining (Table 3.3), indicate that the subsurface sediments contain more oil than those at the surface of the beach. In particular plots MC and D(E)E contain significantly high concentrations of oil when compared to the initial oil loading. Whereas all of the other plots have undergone natural cleaning since the countermeasure experiments, as a result of normal littoral processes during the open-water season, these processes do not appear to have been sufficiently energetic to naturally remove the subsurface oil on these two plots.

Figure 3.5 Blocks of solidified sediments collected near the high-water mark above plots SC and SE (11th August, 1983).

Figure 3.6 Ground view of test plots area on the south shore of Crude Oil Point (13th August, 1983).

Table 3.3 Per cent of Oil Remaining through Time from Initial Oiling - Subsurface Samples (a plus sign indicates an increase in volume).

	1981			1982		1983
CODE	Pre-Test	+8 Days	+40/41 Days	Aug 10	Sept 02	Aug 20
CC	100%	50	5	+112	7	14
CE	100	36	10	33	28	18
MC	100	+530	60	41	76	+106
ME	100	29	18	16	42	8
D(E)C	100	+797	57	+300	17	7
D(E)E	100	+193	1	+113	+173	80
D(B)C	100*	+1063	1	10	0	0
D(B)E	100	+114	1	0	0	0

* Sample lost: value assumed to be 300 mg/kg

3.4 GEOCHEMICAL ANALYSES - 1983 RESULTS

3.4.1 Evaporative Weathering Ratio (SHWR)

Samples were collected only from the two control plots (CC and CE); data from the surface sediments is presented in Table 3.4a. These show unusually high values in comparison to the 1982 data set and there is no evident explanation as to why the values should have increased. Samples were also collected from the subsurface of each of the two plots and the analysis of these produced values of 2.0 and 1.9 respectively for plots CC and CE. These values are similarly higher than the 1982 data set.

3.4.2 Biodegradation (Alkane to Isoprenoid Ratio)

The analysis of surface samples from the two plots shows an increase in values that cannot be immediately explained (Table 3.4b). The analysis of the subsurface samples produced values of 0.7 and 1.4 respectively for plots CC and CE. The subsurface values are more in line with that which would be predicted for these plots. There is no apparent explanation for the increased values and lower levels of biodegradation in the surface samples, whereas the subsurface samples indicate an increased level of biodegradation that follows the long-term trend on these plots.

Table 3.4(a) Geochemical Analyses Results: Evaporative Weathering Ratio (SHWR).

CODE	1981			1982		1983
	Post-Test	+8 Days	+40/41 Days	Aug 08	Aug 29	Aug 17
CC	3.0	2.6	1.6	1.3	1.1	3.3
CE	3.0	2.3	1.4	1.1	1.0	2.0

(b) Geochemical Analyses Results: Biodegradation (Alkane to Isoprenoid Ratio).

CODE	1981			1982		1983
	Post-Test	+8 Days	+40/41 Days	Aug 08	Aug 29	Aug 17
CC	2.1	2.6	1.6	2.2	1.6	3.2
CE	2.7	2.6	2.7	1.6	1.5	2.1

3.5 SUMMARY

The 1981 experiments were undertaken to evaluate a series of selected shoreline cleanup techniques. Observations and sampling have continued to determine the longer term fate of oil on both the experimental and control plots at Crude Oil Point. The most significant findings that relate to the experiments and to the post-experimental data are reported by Owens et al., (1982) and Owens et al., (1983); the primary observations and results from the 1983 field programme are as follows:

- the total hydrocarbon values from the surface sediment samples are lower than those obtained from the 1982 field programme; the highest value from the total hydrocarbon analysis is 32 mg/kg, which represents less than 0.2% of the original oil loading; by comparison the 1981 values ranged from O mg/kg to 370 mg/kg

- a line of contaminated sediments is present along the high-water mark above the plots: samples from this thin band of oiled sediments produced total hydrocarbon values of between 80 and 1,200 mg/kg; these contaminated sediments resulted from the redistribution of material that was pushed up the beach from the plots by wave activity in the intertidal zone

- some oil remains in the subsurface sediments on the mixed crude oil plot (MC), where total hydrocarbon values have remained relatively high since September, 1981; more oil remains in the subsurface sediments of the plots than on the surface due to the greater effectiveness of wave processes on the beach surface; subsurface samples nevertheless have low total hydrocarbon values (excluding plot MC the range is O mg/kg to 430 mg/kg)

4.0 1982 COUNTERMEASURES EXPERIMENT

4.1 INTRODUCTION

Upon completion of the 1981 shoreline countermeasure experiments at Crude Oil Point, it was decided that further information could be obtained by repeating some of the experiments in a more sheltered location. An experimental design was developed to undertake dispersant and mixing experiments on the inner part of Z-Lagoon at a site referred to as Bay 106 (see Fig. 2.1, page 2-2). This very sheltered location has a wide, fine-grained intertidal zone with a maximum fetch area in the order of 1 km. The same two dispersants that were used in the 1981 Crude Oil Point experiments were applied to crude and emulsion intertidal plots at the Bay 106 site. Two control plots were set up in the intertidal zone (Fig. 4.1 and Table 4.1) and two plots for the mixing of backshore sediments were established above the normal limit of wave activity. These latter plots were used to evaluate the mixing of oils that would be stranded by high-water levels. A detailed description of the experimental design used during 1982 in Bay 106 is provided by Owens, et. al., (1983). A list of the experiments and the identification codes that define the plots and also describe the nature of the experiments are provided in Table 4.1.

After application of oil to the intertidal plots on 12th August, 1982, some of the oil was redistributed by the rising tidal water level. The oil coverage extended from the plots up to the high-water swash mark and the dimensions of the plots upon which the intertidal experiments were conducted were extended to this high-water mark. The location of the original plots is given on Figure 4.1 and the limits of the extended plots are shown on Figure 4.2. Samples for total hydrocarbon analysis were collected from the initial oiled plots and from the extended area up to the highest high-water mark on 20th August, 1982. The sampling pattern used during the 1982 and 1983 collection programmed is presented in Figure 4.3. Aerial photographs of the plots immediately following application of the oil and 48 hours later are given in Figure 4.4. Each of the samples that was collected is a composite of four alongshore subsamples. Six additional surface and subsurface samples were taken adjacent to the intertidal oil plots to determine the degree of contamination as a result of redistribution of oiled sediments. The location of these six samples is identified on Figure 4.2. Sampling of the backshore plots, as indicated in Figure 4.3b, involved the collection of samples or subsamples from both berm and back-beach sections of the experimental plots.

Samples that were collected for geochemical analysis were taken at the surface and subsurface in the upper one third of each of the intertidal plots. On the backshore plots, geochemical samples were collected from the surface and subsurface at the berm and in the backbeach areas of each of the four sections that make up the experimental plots (see Fig. 4.3b).

Table 4.1 Plot Identification Codes for 1982 Experiments in Bay 106.

ICC	intertidal crude	- control oil
ICE-E	intertidal emulsion	- flushed by low-pressure dispersion
ICE-W	intertidal emulsion	- control
ICE(B)C	intertidal crude	- dispersed with BP 1100X
ICE(B)E	intertidal emulsion	- dispersed with BP 1100X
ID(E)C	intertidal crude	- dispersed with Corexit 7664
ID(E)E	intertidal emulsion	- dispersed with Corexit 7664
IMC-c	backshore crude	- mixed by rototiller
IMC-e	backshore crude	- control
IMC-c	backshore emulsion	- mixed by rototiller
IME-e	backshore emulsion	- control

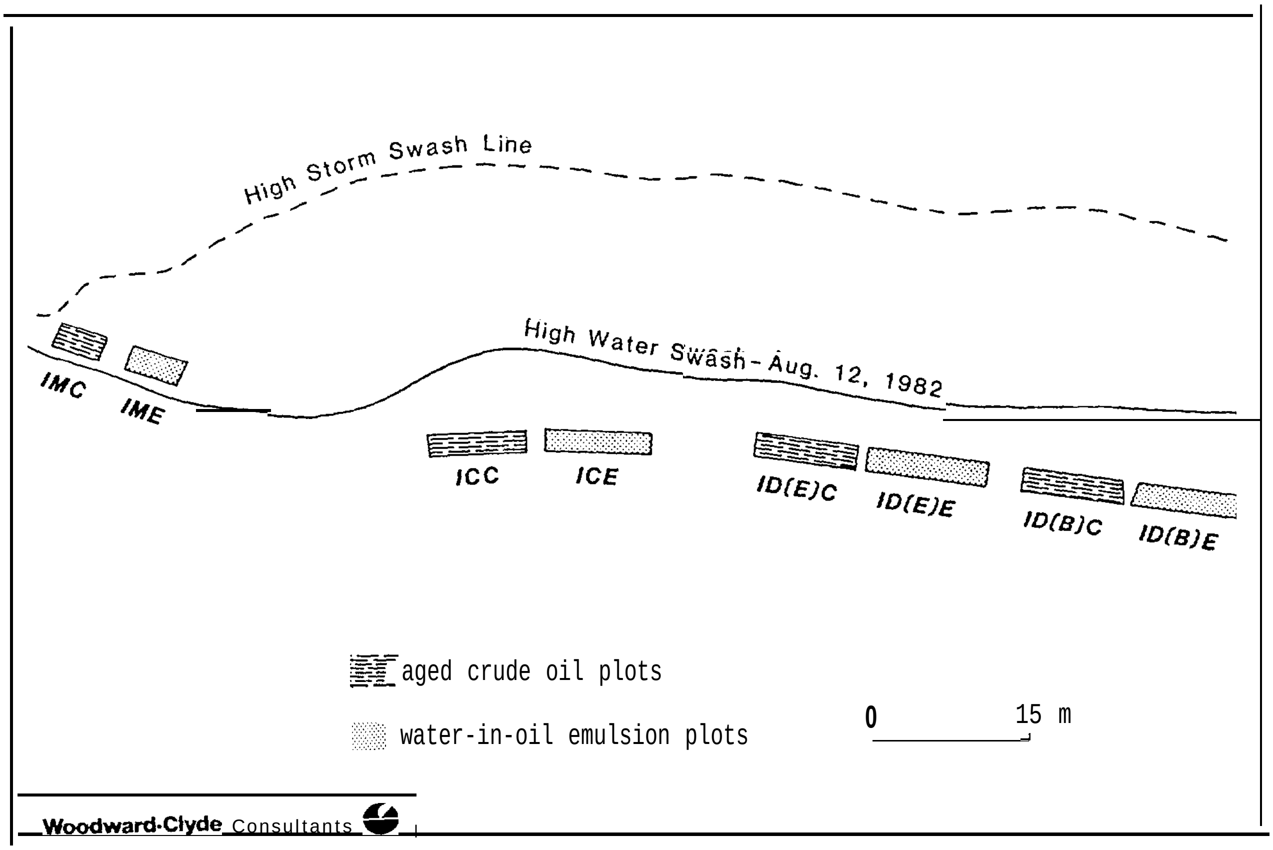


Figure 4.1. Location of 1982 countermeasure and control plots as initially laid down. The test beach is located on Figure 2.1 and the plot identification codes are given in Table 4.1.

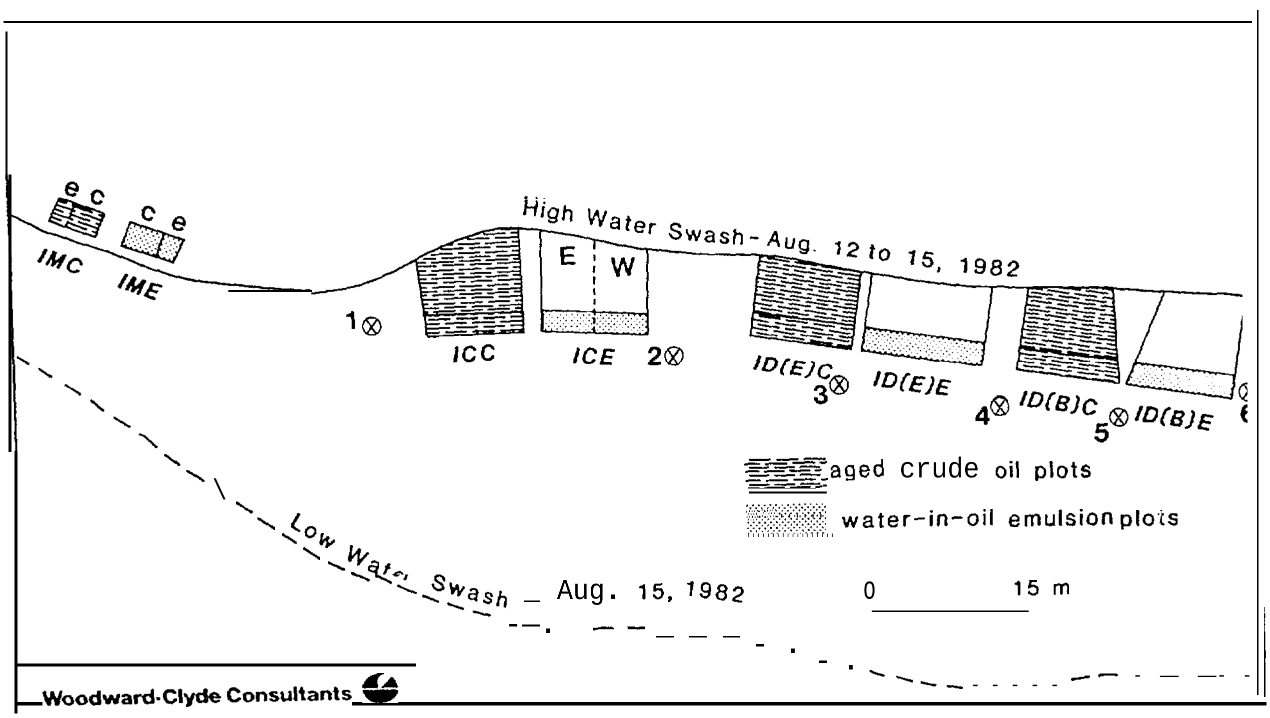
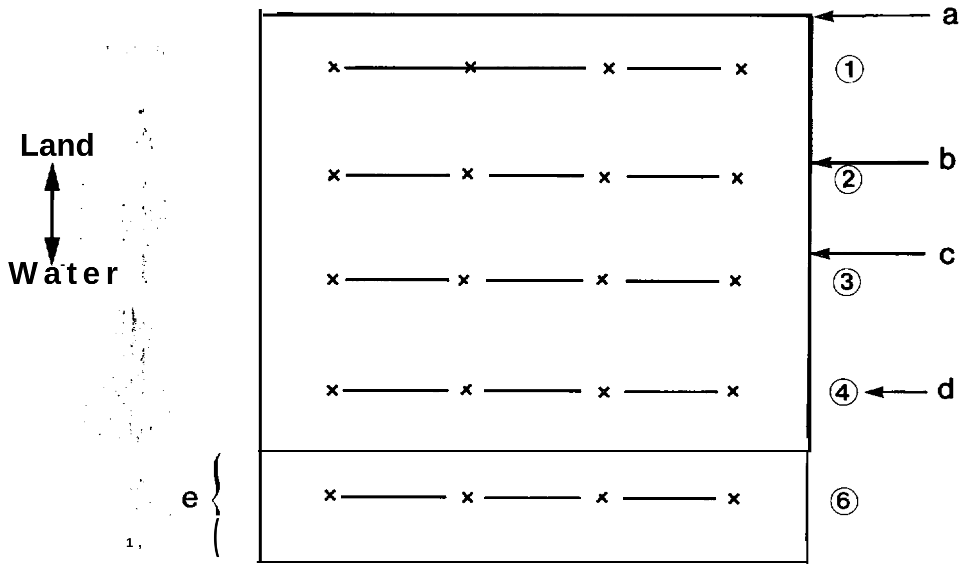


Figure 4.2 Plot dimensions on 13th August, 1982, 24 hours (2 low-tidal cycles) following oiling. Note that the two mixing plots are above the normal high tide swash. The numbered circles with crosses indicate additional 1983 sample sites adjacent to the plots.

a. Intertidal plots (not to scale)



a. highest high-water swash prior to 20 Aug. 1982

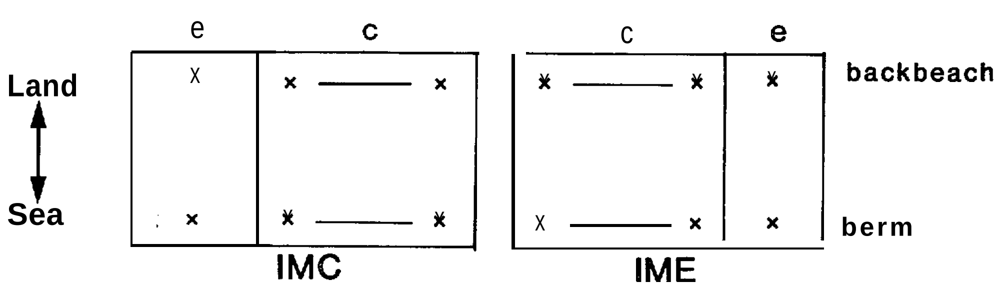
b. high-water swash 12 August, 1982

c. high-water swash 13 August, 1982

d. approx. 2m landward of oiled plot

e. oiled plots

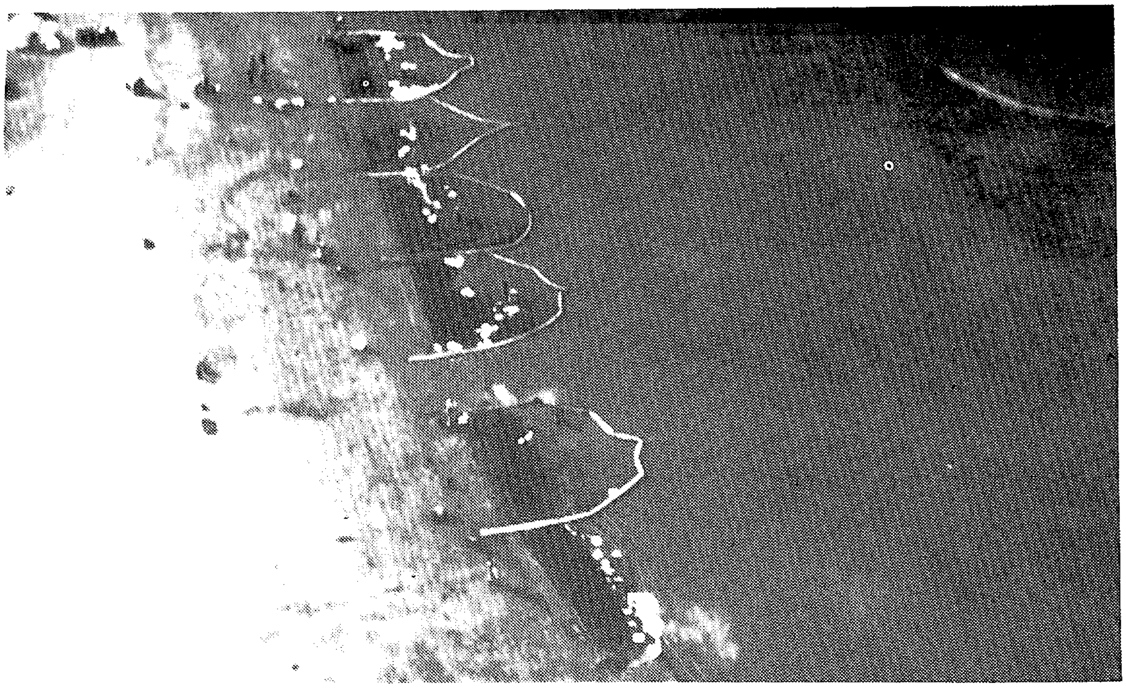
b. Backshore plots



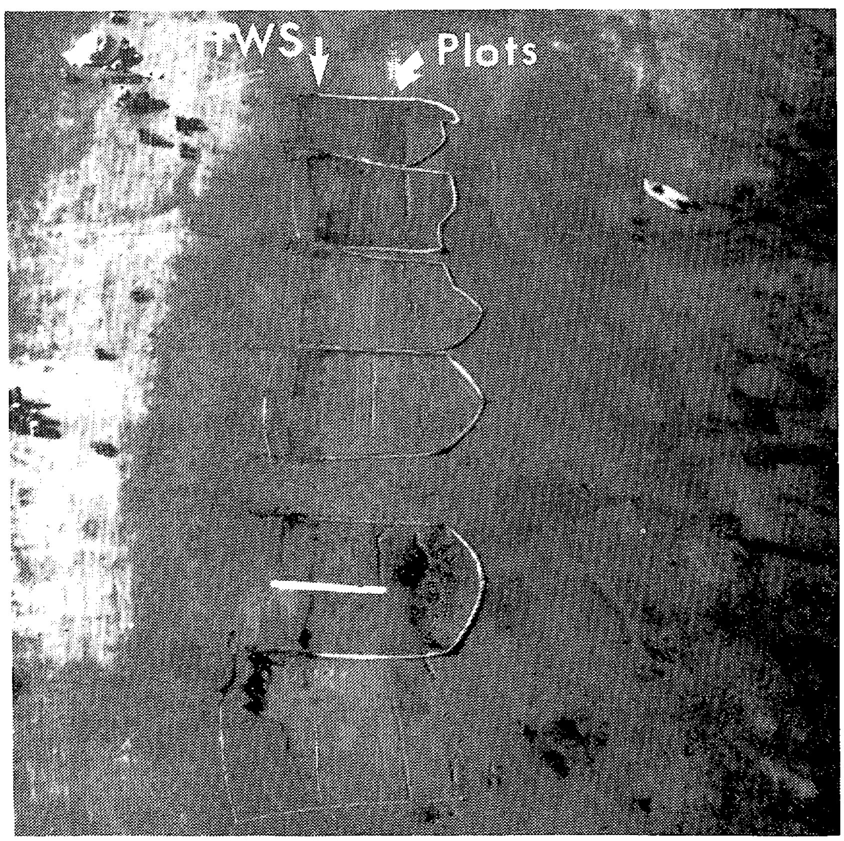
e = control

c = mixed section

Figure 4.3 Sketches of sampling patterns used on experimental and control plots.



(a)



(b)

Figure 4.4 (a) Intertidal plots immediately following application of oil (16:40, 12th August, 1982).

(b) Intertidal plots 48 hours after oiling, 24 hours after the tests (14:20, 14th August, 1982. HWS - High Water Swash on 12th and on 13th August, 1982.

Very little sediment redistribution had taken place on this beach since the 1982 experiments. Numerous small, thin metal pegs that had been used to delineate the plots were still in place in August, 1983. These would have been displaced by even minimal wave activity. It was assumed, on the basis of the 1983 field observations, that no significant sediment redistribution had taken place in the vicinity of the intertidal experimental plots. Similarly, the backshore control plots (IMC and IME) had been unaffected by wave processes, except at the high-water mark berm where it was observed that there had been a slight redistribution of the granule and pebble-sized sediments.

4.2 RESULTS PRIOR TO 1983 STUDY

The data set obtained during 1982 indicates that relatively little oil had penetrated into the fine-grained intertidal sediments. There was a major redistribution of the surface oil from the plots up the beach towards the high-water mark. On average approximately 25 per cent of the original oil remained on the crude oil plots whereas on the emulsion plots approximately 70 per cent was retained.

The hydrocarbon-based dispersant, which was designed to penetrate oil and requires either naturally available energy or added energy to produce the desired effect, did not prove to be successful. The experimental conditions that were used in this 1982 study were designed to provide a direct comparison with the 1981 results and in this sheltered location there was insufficient wave energy available during the sampling period to agitate the oil/dispersant mixture. As a result little oil was removed from this pair of study plots. The other dispersant, which was applied with a fire-hose system, did result in a significant decrease in surface total hydrocarbon values on the crude plot but resulted in little change on the emulsion plot. A low-pressure flushing experiment, on plot ICE-E, resulted in total hydrocarbon values at the surface samples that were in the order of four times greater than on the emulsion control plot. The result of the backshore mixing experiment, using the rototiller, was a reduction of the surface total hydrocarbon values by approximately half.

4.3 INTERTIDAL PLOTS - 1983 TOTAL HYDROCARBON RESULTS

The analysis of samples collected during 1982 indicated the highly variable distribution of oil throughout the intertidal test plots. Following the initial application of the oil (Fig. 4.4a) the rising tidal waters redistributed oil up to the high-water swash limit (Fig. 4.4b). At the time of the last 1982 sample collection (15th September) high concentrations of oil were found to be in the vicinity of Row 2 (the high-water swash limit on 12th August, 1982 - the day on which the oil was applied to the plots), and on Row 6, which represents the oil plots themselves.

Observations in August, 1983 indicated very little visible surface oil. From the air no oil could be discerned in the intertidal zone (Fig. 4.5).

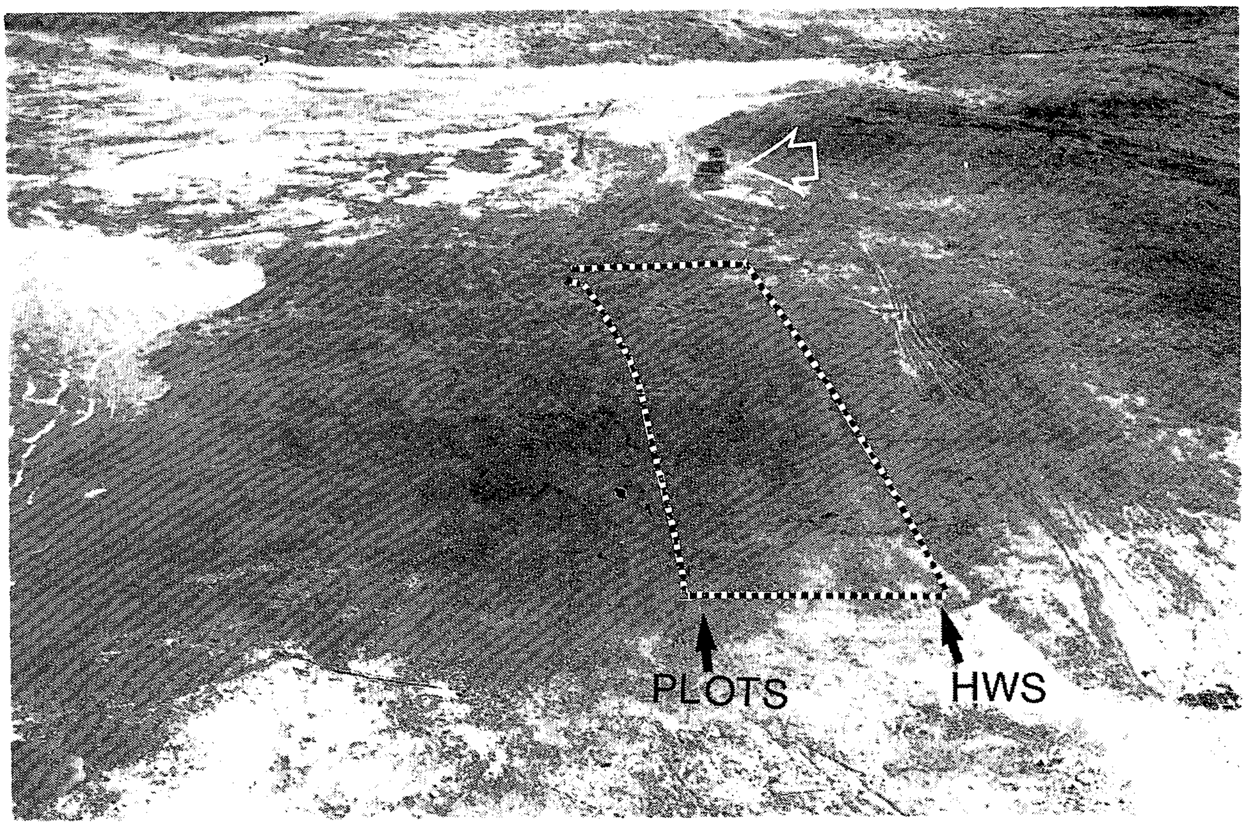


Figure 4.5 Aerial photograph of Bay 106 (12:20, 14th August, 1983). The dashed line indicates the limits of the extended intertidal plots; the open arrow locates the two backshore plots IMC and IME.

On the ground a line of weathered oil on the surface of the beach was identified in the vicinity of the high-water swash line of 12th August, 1983; a line that had been marked by a series of iron pegs (Fig. 4.6). Despite the lack of other visible oil, water that gathered in footprints on the intertidal plots contained sheen in many areas.

The results of the total hydrocarbon analysis on the surface sediment samples show a variable distribution (Table 4.2). Despite this variability some trends can be identified.

Figure 4.6 View to the west taken from ID(E)C at 8m landward of the top of the oiled plot (line 'b' in Figure 4.1a; 10th August, 1983.

Table 4.2 Total Hydrocarbon Results - Intertidal Surface Samples (mg/kg). Row numbers refer to locations shown on Figure 4.1a. Identification codes for the plots (columns) are defined in Table 4.1.

	Row	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E
POST OILING 12 August	6	15,300	8,800	8,800	4,090	4,850	8,810	8,280
PRE-TEST 13 August (day O)	1							
	2	11,000	1,730	1,730	21,200	2.080	9,690	5,220
	3							
	4	160	270	270	70	690	2,860	540
	6	1,460	6,330	6,330	4,360	1,680	840	7,340
POST TEST (+1 day)	1							
	2		11,000	1,600	12,800	2,160	20,400	40,900
	3		9,660	2,390	1,980	1,320	18,500	34,000
	4		430	310	130	230	30	8,960
	6		24,000	5,910	420	1,520	8,300	20,200

Table 4.2 cont.

	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E
1		70	50	80	910	1,140	390
2	6,860	1,170	230	8 770	15,200	27,900	29,100
3	620	33,600	1,040	930	2 180	10,500	6,340
4	100	460	260	260	530	5,060	4,810
6	5,240	15,900	4,630	120	1,510	2,760	11,800

POST TEST
22 August
(+7 days)

	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E
1	400	40	230	330	450	320	530
2	200	1,370	8,210	5,530	1,520	12,300	6,870
3	650	15,100	530	270	380	1,730	1,810
4	620	1,180	200	1,290	1,200	3,240	1,590
6	2,130	11,900	830	30	130	170	690

POST
TEST
15 September
(+33 days)

	ICC	ICE-E / ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E
1	72	30	87	98	100	87
2	9,100	1,300	3,100	6,400	11,000	5,300
3	130	450	160	410	1,600	210
4	210	1,400	69	310	260	1,900
6	380	7,800	170	49	130	170

1983
20 August

ICC ICE-E ICE-W ID(E)C ID(E)E ID(B)C ID(B)E

If all of the intertidal plots are considered together there has been a general decrease in the total hydrocarbon values on each row since the countermeasure experiments (Table 4.3) and the 1983 mean values indicate a continuing progressive reduction in the total hydrocarbon values. This set of mean values suggests that subsequent to the countermeasure experiments (Day +1) there has been a reduction in the degree of contamination of the surface sediments that has been due to natural processes in the intertidal zone. The reduction of total hydrocarbon values has been greater following Day +7 than occurred between Day +1 (post-test) and Day +7.

If the comparison is made between all samples collected at one time from each of the plots, the same trend of a progressive reduction in the surface total hydrocarbon values since Day +7 (22nd August) is also evident (Table 4.4) .

Although some trends were evident between the plots in the early data sets, as a result of the countermeasure experiments, these differences had been largely equalised by the August, 1983 sample period (Table 4.4). The mean value of all of the August, 1983 samples from all six plots is 1,707 mg/kg, as compared to 5,603 for 22nd August, 1982 and 2,616 for 15th September, 1982. Significantly, the standard deviation for the 20th August, 1983 mean values given in Table 4.4 is only 638.

The results of the total hydrocarbon analysis from the subsurface samples (Table 4.5) indicate reductions in almost every location. In particular, the reduction in the values on the ID(E) and on the two ID(B) plots are significant.

Table 4.3 Total Hydrocarbon Results - Mean Values by Row for each set of Surface Samples (mg/kg).

Row	1982 Post Oiling	1982 Day 0	1982 Day +1	1982 Day +7	1982 Day +33	1983
1				440	328	79
2		8,487	14,81o	12,747	5,143	6,033
3			11,308	7,887	2,924	493
4		765	1,682	1,640	1,331	691
6	8,355	3,668	10,058	5,994	2,264	1,450

Table 4.4 Total Hydrocarbon Results - Mean Values of all Surface Samples by Plot for selected Dates (mg/kg).

	ICC	ICE	ID(E)C	ID(E)E	ID(B)C	ID(B)E
22nd August, 1982	3,205	4,356	2,032	4,o66	9,472	10,488
15th September, 1982	719	3,959	1,490	3,680	3,552	2,298
20th August, 1983	1,978	1,944	717	1,453	2,618	1,533

Table 4.5 Total Hydrocarbon Results - Intertidal Subsurface Samples (mg/kg). Row numbers refer to locations shown on Figure 4.1a. Identification codes for the plots (columns) are defined in Table 4.1.

	Row	ICC	ICF-E	ICF-W	ID(F)C	ID(F)E	ID(B)C	ID(B)E
POST OILING 12 August	6	-	-	-	-	-	-	-
PRE-TEST 13 August (day 0)	1							
	2	50	0	0	30	0	370	0
	3							
	4	0	0	0	0	0	0	0
	6	40	90	90	5,440	0	50	410
POST TEST (+1 day)	1							
	2		0	30	40	100	200	1,320
	3		90	50	0	30	40	30
	4		0	0	0	0	7,130	60
	6		40	80	460	0	0	50

Table 4.5 cont.

Period	Row	ICC	ICE-E	ICE-W	ID(E)C	ID(E)E	ID(B)C	ID(B)E
POST TEST 22 August (+7 days)	1	0	0	0	0	0	0	0
	2	0	0	0	0	100	70	30
	3	0	30	0	50	0	50	0
	4	0	0	0	0	0	0	0
	6	0	30	0	0	0	0	0
POST TEST 15 September (+33 days)	1	50	-	30	0	0	30	150
	2	50	180	5,720	1,27'0	0	2,300	7,910
	3	420	180	0	2,530	200	2,230	360
	4	0	90	0	0	30	3,240	4,340
	6	0	270	0	0	0	210	260
1983 20 August	1	28	0		0	0	0	0
	2	250	0		350	86	48o	89
	3	110	160		22	0	78	0
	4	20	41		0	0	88	330
	6	21	440		20	0	0	0

4.4 INTERTIDAL PLOTS - 1983 GEOCHEMICAL RESULTS

The Saturated Hydrocarbon Weathering Ratios for the two control plots indicate that the values from August, 1983 are very similar to those from September, 1982 (see Table C.3: Owens et al., 1983). The values for the ID(E) plots also are similar to those from September, 1982; whereas the ID(B) plots have reduced from 16.0 to the values given in Table 4.6a. The values for ID(B) are artificially high as the ratio is influenced by the presence of solvents in the dispersant that was used in this countermeasure experiment. The subsurface SHW Ratios show no significant trends, and the total hydrocarbon content of the subsurface sediments is so low that the ratios have little direct significance.

The Alkane/Isoprenoid ratios show that a significant increase in surface microbial degradation occurred between the last sample period of September, 1982 and the August, 1983 samples (Table 4.6b). It must be noted that the ID(B) samples are again influenced by the presence of solvents in the experimental dispersant.

Table 4.6 (a) SHWR Results for 1982 Intertidal Plots.

	ICC	ICE	ID(E)C	ID(E)E	ID(B)C	ID(B)E
Sept.-1982-surface	1.6	1.8	1.7	1.4	16.0	16.0
1983 surface	1.62	1.51	1.39	1.42	12.41	13.96
1983 subsurface	1.46	1.82	1.09	2.50	17.40	2.80

(b) Alkane/Isoprenoid Ratios

Sept.-1982-surface	2.8	2.7	2.6	2.6	4.6	4.6
1983 surface	1.36	1.70	2.02	1.46	3.73	3.90
1983 subsurface	1.88	0.59	2.50	0.38	3.64	1.92

The results of the geochemical analysis indicate that for the control and ID(E) plots the surface sediments have undergone little evaporative weathering between September, 1982 and August, 1983, but that within the surface sediments there has been an increase in microbial degradation over that same time period.

4.5 BACKSHORE PLOTS - 1983 TOTAL HYDROCARBON RESULTS

The backshore plots had not been affected by marine processes at the time of the 1983 observation programme (Figures 4.5 and 4.7). The surface sediment samples on the landward side of the berm have undergone a general decrease in hydrocarbon content between September, 1982 and August, 1983; all of the backbeach sections of the plots have hydrocarbon contents that decreased by greater than 30 per cent over this time period (Table 4.7) The two mixed berm sections show virtually no change between September, 1982 and August, 1983; whereas the two berm control plots have undergone a significant increase in their total hydrocarbon contents. The high value of 15th September, 1982 on the backbeach IME control plot is most probably an artifact of sampling a localised pool or lump of oil.

The total hydrocarbon results from the surface sediment samples show that, in all cases, the concentration of oil on the mixed plots is lower than on the adjacent respective control plot (Table 4.7). In the case of the crude oil plots (IMC) there remains approximately half the concentration of oil in the mixed surface sediments as compared to the control surface sediments.

All of the samples collected from the subsurface of the backshore plots have decreased total hydrocarbon contents between September, 1982 and August, 1983 (Table 4.8). Despite these reductions in the total hydrocarbon values over this time period there is a significant difference between the mixed and control plots, with higher values on the mixed plots. The mixing procedures that were used during the experiment resulted in the burial of surface oil and that oil remains in significant amounts in the subsurface sediments after one year.

Table 4.7 Total Hydrocarbon Results - Backshore Surface Samples (mg/kg).

	IMC control	IMC mixed	IME mixed	IME control	
backbeach	23,800	24,200	42,200	18,400	PRE-TEST 14 August 1982
berm	106,000	56,500	17,100	12,400	
backbeach	20,600	12,700	12,300	34,500	POST TEST 15 August (day O)
berm	66,900	23,200	9,270	7,730	
backbeach	38,200	14,500	24,800	40,000	PoST TEST 22 August (+7 days)
berm	88,600	18,700	13,800	8,640	
backbeach	32,600	18,200	16,700	65,200	POST TEST 15 September 1982 (+3 1 days)
berm	57,100	31,100	8,510	5,350	
backbeach	22,000	11,000	11,000	14,000	1983 20 August
berm	62,000	31,000	7,400	11,000	

Table 4.8 Total Hydrocarbon Results - Backshore Subsurface Samples (mg/kg).

		IMC control	IMC mixed	IME mixed	IME control
PRE-TEsT 14 August	backbeach	100	270	360	140
	berm	2,200	7,010	17,900	14,500
POST TEST 15 August (day 0)	backbeach	570	8,400	11,900	120
	berm	*1,420*	-	*12,600*	*11,200*
POST TEST 22 August (+7 days)	backbeach	170	9,400	15,100	220
	berm	1,860	26,900	7,670	11,500
POST TEST 15 September (+31 days)	backbeach	590	7,510	15,100	3,050
	berm	7,380	22,500	11,500	12,800
1983 20 August	backbeach	480	4,500	5,500	280
	berm	930	2,300	7,800	7,100

The short-term changes between September, 1982 and August, 1983 described above must be seen in the context of the long-term objectives of the experiment, which were to determine if mixing could provide any beneficial contribution to shoreline countermeasures. If the amounts of oil laid down on the beach, prior to the mixing tests, are compared with the August, 1983 total hydrocarbon results it is apparent that on the surface there was a greater reduction in the total hydrocarbon on the mixed plots than on the control plots (Table 4.9). It can be stated therefore that the mixing procedures did reduce the total hydrocarbon concentrations of the surface sediments, and that this reduction is clearly visible after one year (Figure 4.8), both in terms of the total hydrocarbon concentrations (Table 4.7) and in terms of the per cent reduction of oil (Table 4.9). In a comparison of the amounts of hydrocarbons in the subsurface sediments, there has been a major increase in the total hydrocarbon concentrations on the backbeach mixed plots (Table 4.8). In the backbeach sections mixing has had no beneficial effect, in fact it has made sediments that were originally relatively clean (total hydrocarbon values less than 360 mg/kg) into contaminated materials (total hydrocarbon concentrations greater than 4500 mg/kg). The subsurface sediments on the berm sections do not show this trend. However the hydrocarbon concentrations are greater on the mixed sections than on the control sections (Table 4.8).

Table 4.9 Backshore Plots - Per cent Oil Remaining (Comparison between 14th August, 1982 and 20th August, 1983).

(a) Surface

	IMC		IME	
	control	mixed	mixed	control
Backbeach	92%	45	26	76
Berm	58	55	43	89

(b) Subsurface

	IMC		IME	
	control	mixed	mixed	control
Backbeach	480%	1667	1528	200
Berm	42	33	44	49

Table 4.10 Saturated Hydrocarbon Weathering Ratios for 1982 Backshore Plots : 1983 samples were collected on 17th August. Berm samples were collected only in 1983.

(a) Berm (1983)

	Control	Mixed
IMC - surface	1.5	1.6
IMC - subsurface	2.4	2.1
IME - surface	1.7	1.7
IME - subsurface	2.0	2.0

(b) Backbeach (1982 - 1983)

	Control				Mixed			
	1982			1983	1982			1983
IMC - surface	2.0	2.2	1.7	1.4	2,6	2.0	2.0	1.7
IMC – subsurface				1.9				1.9
IME - surface	2.3	1.8	2.0	1.5	2.3	2.0	1.6	1.6
IME – subsurface				1.6				2.1

4.6 BACKSHORE PLOTS - 1983 GEOCHEMICAL RESULTS

The results from the 1983 analysis (Table 4.10) of the berm and the backbeach samples show, consistently, that the surface samples have undergone a greater degree of evaporative weathering than have the subsurface samples on both the crude oil and the emulsion plots and also on the control and mixed plots. The values for all the surface samples fall between 1.4 and 1.7, whereas those for the subsurface samples range between 1.6 and 2.4. The high degree of uniformity between the surface samples suggest that they have all undergone similar physical weathering processes and that in the long term the mixing activity of the rototiller did not promote physical weathering to any greater degree than had occurred on the control plots.

Table 4.11 Alkane/Isoprenoid Ratios for 1982 Backshore Plots: 1983 samples were collected on 17th August. Berm samples were collected only in 1983.

(a) Berm *(1983)*

	Control	Mixed
IMC - surface	2.2	2.3
IMC - subsurface	2.3	2.3
IME - surface	2.1	2.3
IME - subsurface	2.3	2.2

(b) Backbeach (1982 - 1983)

	Control				Mixed			
	1982			*1983*	*1982*			1983
IMC - surface	2.6	2.7	2.6	1.9	2.5	2.7	2.6	2.2
IMC - subsurface				2.1				2.1
IME - surface	2.3	1.8	2.0	1.4	2.6	2.6	2.4	2.4
IME - subsurface				2.0				2.3

The Alkane/Isoprenoid ratios indicate a narrow range of values between 1.9 and 2.4, with the single exception of the surface backbeach sample from IME-e, the control plot (Table 4.11). These diagnostic ratios indicate that within one year after the experiments at this site some microbial degradation had occurred in both the surface and subsurface sediments. If all 1982 and 1983 values are seen as means the following pattern emerges: crude control - 2.6/2.1, crude mixed - 2.6/2.2, emulsion control - 2.0/1.9, emulsion mixed - 2.5/2.3. Although the trend is not major, it appears that more microbial degradation took place on the crude plots than on the emulsion plots.

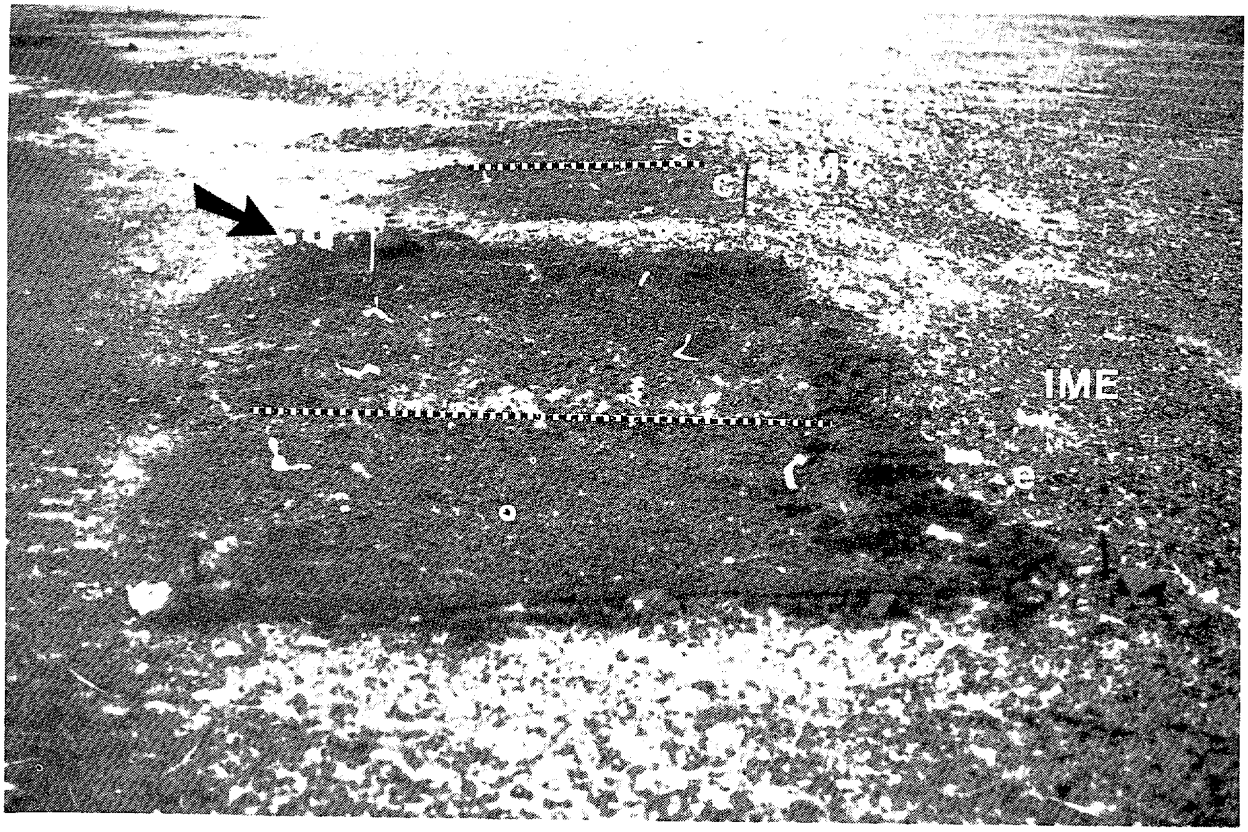
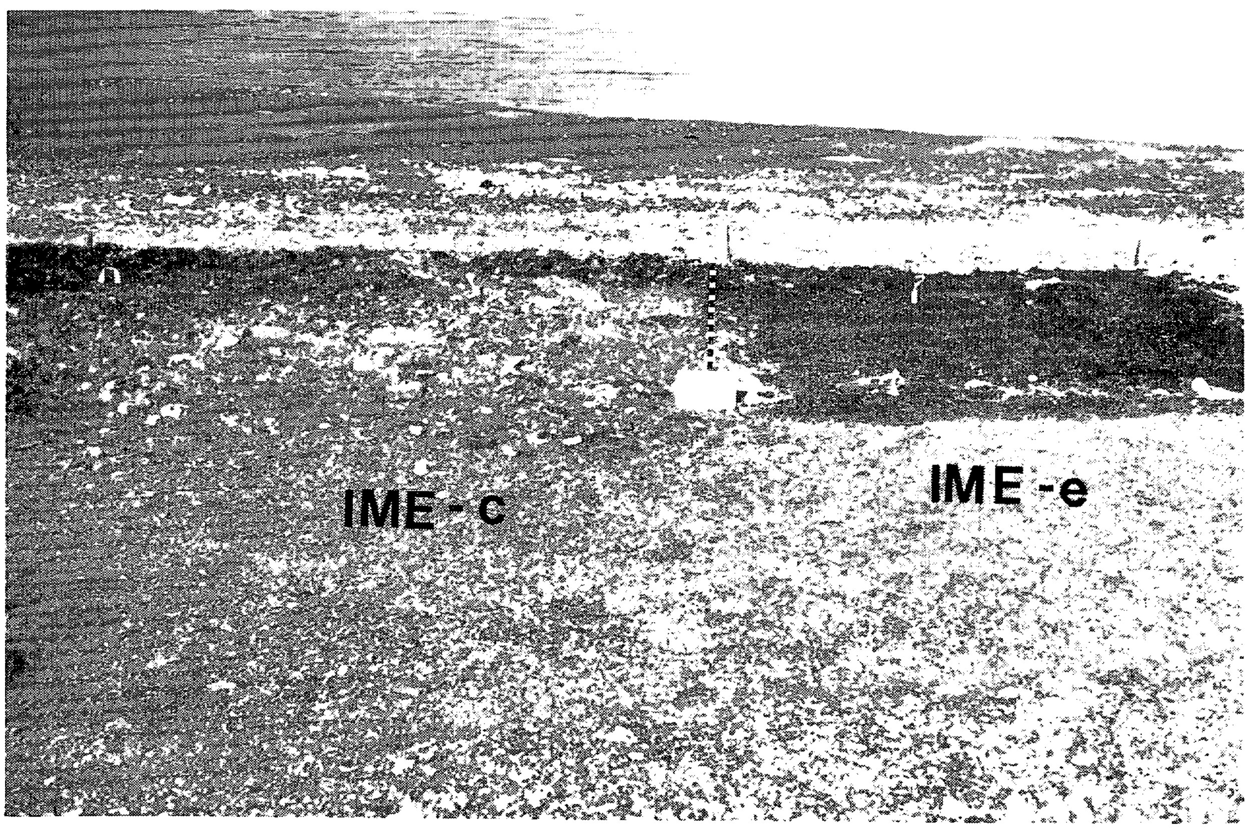


Figure 4.7 Ground view of Bay 106 backshore plots (e = control: c = mixed section) . The sea is to the right in this view: 10th August, 1983. The scale located by the arrow is 25cm in length.



'Figure 4.8 Close-up of backshore emulsion plot, with control section at right (15th August, 1983).

4.7 SUMMARY

The changes that have been recorded as a result of the total hydrocarbon analyses are summarised and compared to the results from the 1980 and 1981 experiments in 'Z-Lagoon':

(a) Intertidal Plots

- little oil was visible in the intertidal zone from ground observations; the exception being a patchy line in the vicinity of the mean high-water mark

- there has been a progressive decrease in the total hydrocarbon values on each row; this has been due primarily to natural processes as the reduction in total oil concentrations has decreased significantly since 22nd August, 1982, seven days after the test: the range of mean plot values immediately post-test was 3,800 to 26,000 mg/kg and for 22nd August, 1982 was 2,000 to 10,500 mg/kg, versus a range on 20th August, 1983 of 720 to 2,000 mg/kg

- although all total hydrocarbon values in the surface sediments had decreased between September, 1982 and August, 1983, this decrease was significantly lower than occurred on the countermeasure plots at Crude Oil Point over the same corresponding post-test sampling period: at the beginning of the second open-water season at Crude Oil Point a mean value of 124 mg/kg characterised all eight intertidal plots - as compared to a mean of 1,700 mg/kg for the surface sediments of Bay 106: this difference is due to the higher wave-energy levels that affect the east-facing beaches of Crude Oil Point

- the total hydrocarbon values from the surface sediments on the low-energy crude control plot in Bay 103 (L-1) showed a slower decrease than Bay 106 (progressively from 4723 mg/kg, 3263 mg/kg to 627 mg/kg respectively for the second, third and fourth open-water seasons); therefore under the same conditions in Z-Lagoon the oil from plot L-1 was naturally removed at a much slower rate - this is largely a result of the character of the intertidal sediments rather than the wave-energy levels or the countermeasure experiments on Bay 106

- if the data from Row 6 (i. e. the plots) on Bay 106 are reviewed over the sampling period there was a large decrease in the total hydrocarbon concentrations of the surface sediments during the first 24 hours after the oil was laid down; before the tests approximately 55% of the surface oil was lifted from the plots by the rising tide

- the most significant result from the Bay 106 experiments is that there was probably a greater reduction in oil content on the surface of the beach as a result of the sediment characteristics than as a result of the countermeasure experiments that were conducted in the intertidal zone

- the analysis of the subsurface samples on Bay 106 indicates that the total hydrocarbon values are lower after one year than was recorded at either Crude Oil Point or on plot L-1; this can be attributed to the lower amount of penetration that occurred due to the fine nature of the sediments and to the water-saturated conditions of much of the intertidal zone in Bay 106

(b) Backshore Plots

- on the backshore experimental plots the mixing procedures succeeded in significantly reducing the total hydrocarbon content of the surface sediments - both in terms of the relative concentrations and in terms of the percentage oil remaining after one year

- on the backshore experimental plots the mixing procedures did cause a significant increase in the concentrations of total hydrocarbon in the subsurface sediments on the backbeach sections but there appeared little difference after one year between the subsurface control or mixed sediments on the berm sections

- the geochemical analyses indicate that the surface sediments, on both backshore control and mixed plots, have undergone greater evaporative weathering than have the subsurface sediments; by comparison, the surface and subsurface sediments have undergone relatively little microbial degradation up to August, 1983

5.1 INTRODUCTION

Two nearshore oil-spills were conducted on the eastern margin of Ragged Channel during 1981. At the Bay 9 site (see Fig. 1.2, page 1-3) a discharge of 15 m^3 of crude oil, which had been mixed with 75 m^3 of seawater and 1.5 m^3 of dispersant resulted in the oiling of approximately 300 m of the adjacent shoreline. Sediment samples were collected to determine the amounts of the oil-dispersant-water mixture in the intertidal sediments. Only small amounts of this mixture reached the shoreline and total hydrocarbon contents of the sediment samples were less than 0.2 per cent one day after the experiment. At the Bay 11 site (Fig. 1.2) 15.0 m^3 of crude oil were discharged on the water surface. The spill was confined by means of a boom and an estimated 5.6 m^3 of oil contaminated the shorezone. A total of approximately 9,000 m^2 of the intertidal zone was contaminated during this experiment. Sample collection and mapping of the distribution of the oil were undertaken on the Bay 11 beaches in 1981, 1982 and 1983 as part of an ongoing programme to assess the long term fate of this stranded oil.

5.2 RESULTS PRIOR TO 1983

At the Bay 9 site less than one per cent of the total amount of oil that was spilled in the nearshore environment was stranded in the shorezone. The samples that were collected in 1981 and 1982 for total hydrocarbon analyses yielded only one value that was greater than the detection limit of the analytical technique (20 mg/kg). In 1982 none of the samples produced values above the detection limit. The more detailed geochemical analysis using GC techniques provided values in the range of 1.8 to 25.0 mg/kg from the surface beach sediments that were sampled during 1982 in Bay 9. There was some degree of contamination that was recorded using the detailed analytical methods, but these levels of contamination are extremely low.

The initial oiling of the Bay 11 beach in 1981 resulted in the contamination of approximately 9,000 m^2 of the intertidal zone. The mean total hydrocarbon content of the surface sediments after the spill was approximately 7,000 mg/kg, ranging between 500 and 18,000 mg/kg. The surface coverage of the oil and also the total hydrocarbon values were very variable over short distances. The highest concentrations of oil occurred in the locations of coarse sediments, on the crest of a ridge in the lower one-third of the intertidal zone and on the beach-face in the upper intertidal zone. Low oil concentrations occurred primarily in the areas of fine-grained sediments which were associated with either small streams that cross the intertidal zone or a topographical low between the ridge crest and the beach-face slope.

One year after the spill, in 1982, the mean surface value in the intertidal zone was in the order of 4,000 mg/kg and the surface values ranged from 620 to 11,800 mg/kg. Subsurface total hydrocarbon values were lower than those from the surface sediments ranging between 60 and 5,250 mg/kg, with a mean in the order of 1,000 mg/kg. In 1982 there was significant spatial variation in the surface distribution of the oil. In particular, the highest oil contents were again on the ridge crest and on the beach-face slope.

Geochemical analyses of the stranded oil indicated that evaporative weathering was most active during the first open-water season and continued to be a significant process through into 1982. By comparison biodegradation occurred only between the mid-September 1981 and the early August, 1982 sample periods. The actual area of contamination increased slightly in 1982 as the oil became redistributed across the intertidal zone. However, this was offset by a decrease in the concentrations of the oil-in-sediments.

5.3 RAGGED CHANNEL - BAY 9 RESULTS FROM 1983

Samples were collected from the upper, middle and lower sections of the intertidal zone along profiles 100 and 300 (see Owens et al., 1983). None of the twelve surface and subsurface samples collected along these profiles contained hydrocarbons above the detection limit (20 mg/kg) (see Table A.5 in Appendix A). This beach has essentially been free of oil in both the 1982 and 1983 field seasons. Some hydrocarbons are present in the shore zone as the geochemical analysis of the sediment samples has yielded values that range between O and 11.6 mg/kg. The results of the geochemical analysis are presented in Table 5.1. The ratios indicate that there has been significant physical weathering of the hydrocarbons but that little microbial biodegration had occurred. With one exception (P1OO-U) all of the SHWR and Alkane/Isoprenoid ratios are lower in 1983 than was determined from the 1982 sample collection programme (Table 5.1). At these low total hydrocarbon concentrations it is possible that some biogenic artifacts influence the ratios.

Table 5.1 Geochemical Analysis Results: Bay 9.

	PROFILE	DATE	SHWR	ALK/ISO
(a) 1981	P200-M	31 Aug 81	1.4	-
	P200-L	31 Aug 81	1.5	-
(b) 1982	P100-U	08 Aug 82	1.1	1.9
	P100-M	08 Aug 82	1.3	3.6
	P100-L	08 Aug 82	1.1	2.2
	P300-U	08 Aug 82	1.6	2.8
	P300-M	08 Aug 82	1.7	3.9
	P 300-L	08 Aug 82	1.5	3.9
(C) 1983	P100-U	10 Aug 83	2.1	0.8
	P100-M	10 Aug 83	1.2	1.4
	P100-L	10 Aug 83	0	0
	P300-U	10 Aug 83	1.1	1.5
	P 300-M	10 Aug 83	1.2	0.8
	P300-L	10 Aug 83	1.2	1.6

5.4 RAGGED CHANNEL - BAY 11 RESULTS FROM 1983

As part of the 1983 field programme the beach profiles that had been established on this section of shoreline (Fig. 5.1) were resurveyed, samples were collected along Profiles 1, 3, 6 and 8, and a series of observations were made on the surface oil cover in the intertidal zone. In figure 5.1 the intertidal zone is indicated by the dot pattern.

In previous reports there has been an inconsistency between sample locations and profile lines. Tables 5.2 and 5.4, and Figure 5.1 are the revised and correct versions that replace all previous similar diagrams and tables that relate to the Bay 11 sample locations.

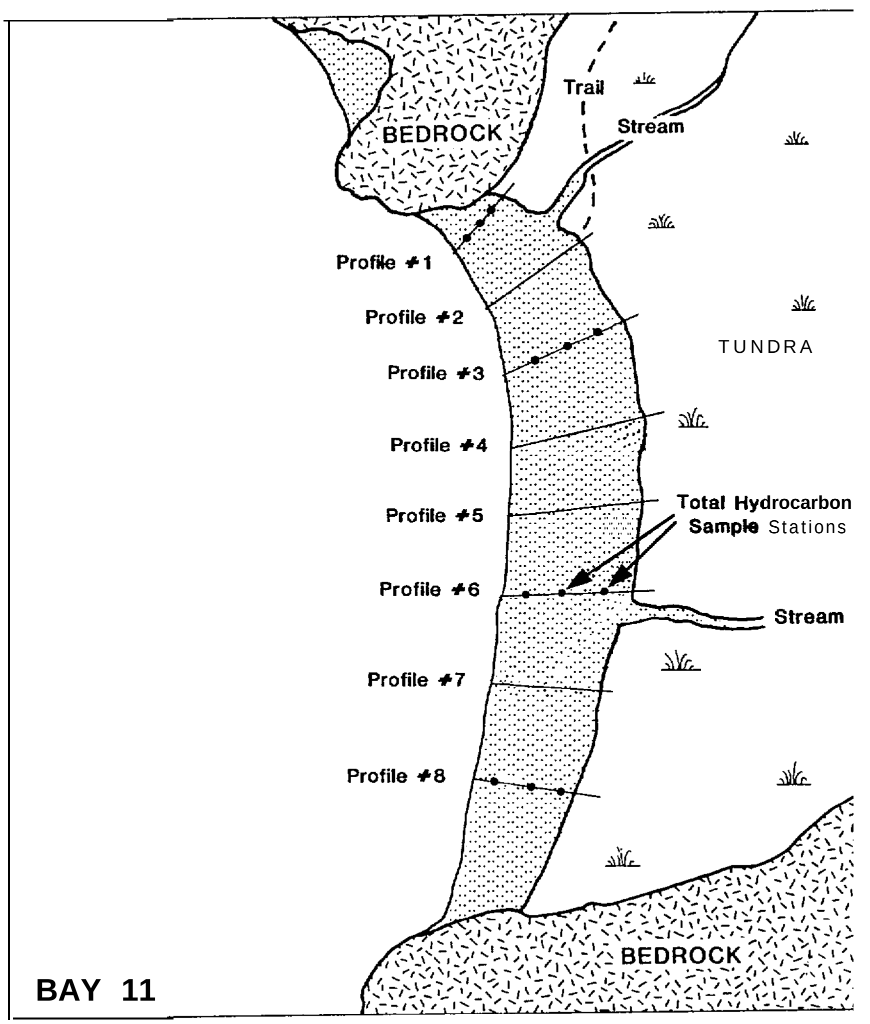


Figure 5.1 Location of profile lines and sample sites in Bay 11.

5.4.1 Sample Analysis Results

The total hydrocarbon data (Tables 5.2 and 5.3) indicates that there has been a marked increase in the hydrocarbon concentration in the surface sediments of the upper intertidal zone, particularly in the central sections of the beach on Profiles 3 and 6. It is apparent that there has been a progressive decrease in the amount of oil in the lower sections of the intertidal zone and that some of the oil may have been transported offshore but oil has almost certainly been moved up the beach towards the high-water mark (Table 5.3). Comparison of the data from 1981 to 1983 suggests that the surface sediments in the north, along Profile 1, and in the south, along Profiles 6 and 8, have become progressively cleaner in terms of the total hydrocarbon content. There has been an increase in the total hydrocarbon concentrations in the upper and middle parts of the intertidal zone on Profiles 3 and 6 (Table 5.2).

The increase in values on profiles 3 and 6 is associated with the development of an asphalt pavement on the beach-face slope. The oil that remains in the intertidal zone has been concentrated to some degree on the ridge crest in the lower part of the beach but primarily on the beach-face in the central section between profiles 2 and 6. This concentration of the remaining oil accounts for the increase in the mean value of the surface upper intertidal samples collected in 1983 (Table 5.3) and the corresponding overall mean value.

The subsurface sediments show a range of 82 to 1,500 mg/kg in the upper zone; 420 to 7,500 mg/kg in the middle zone; and 29 to 1,200 mg/kg in the lower zone. The higher values at the middle level are probably due to the greater degree of sediment mixing that takes place in this central section of the intertidal zone.

The geochemical analysis (Table 5.4) indicates that there have been significant levels of evaporative weathering since 1982. The biodegration ratios (Alkane/Isoprenoid) are more variable, ranging between 0.2 and 2.5, but there is a trend of lower values in the lower part of the intertidal zone and higher values in the upper part of the intertidal zone.

Table 5.2 Total Hydrocarbon Content (mg/kg): Bay 11

		1981			1982	1983
		20 Aug	28 Aug	15 Sept	10 Aug	16 Aug
PROFILE 1	upper surface	7,050	2,840	5,920	3,370	910
	subsurface	90	220	tr	1,180	82
	mid surface	480	6,400	1,920	4,040	830
	subsurface	50	320	330	270	420
	low surface	18,000	4,540	1,860	860	110
	subsurface	60	190	240	60	43
PROFILE 3	upper surface	3,440	109	260	9,730	27,000
	subsurface	140	140	tr	1,500	1,500
	mid surface	4,800	11,000	12,000	2,690	3,100
	subsurface	60	110	240	540	2,300
	low surface	470	2,050	5,820	620	60
	subsurface	200	380	tr	160	29
PROFILE 6	upper surface	16,000	18,000	17,000	11,800	58,000
	subsurface	560	5,800	220	5,250	550
	mid surface	6,090	6,540	6,500	2,190	14,000
	subsurface	170	450	360	120	1,100
	low surface	7,340	8,270	3,640	4,080	2,800
	subsurface	180	500	540	160	1,200
PROFILE 8	upper surface					3,300
	subsurface					220
	mid surface					1,800
	subsurface					7,500
	low surface					1,400
	subsurface					470

Table 5.3 Summary of Total Sediment Hydrocarbon Content (mg/kg).

		1981			1982	1983
		20 Aug (day 0)	28 Aug (day +8)	15 Sept (day +25)	10 Aug	16 Aug
SURFACE	upper intertidal	8,800	7,000	7,100	8,300	22,302
	middle intertidal	3,800	7,900	6,800	2,970	4,932
	lower intertidal	8,600	5,000	3,800	1,853	1,092
	mean	7,100	6,600	5,900	4,374	9,442
SUBSURFACE	upper intertidal	260	2,050	70	2,643	588
	middle intertidal	90	2'90	310	310	2,830
	lower intertidal	150	360	260	126	435
	mean	170	900	210	1,026	1.284

5.4.2 Surface Oil Cover Surveys

A series of observations was carried out during the field study in order to estimate the amount of oil that remained on the intertidal beach of Bay 11. In order to assess the accuracy of these estimates it was decided to undertake more than one set of observations. A distinction is drawn between estimates, which were obtained as a single assessment of the surface oil cover, and observations, which were obtained at a 2 m interval along 19 profile lines across the intertidal zone. The sequence of estimates and observations was as follows:

- estimate from helicopter at approximately 100 m elevation; on a damp day following a period of rain (12th August, 1983)
- estimate at ground level from a rock outcrop at the north end of the beach at approximately 5 m elevation; on the same day as the aerial estimate noted above
- observations along the profile lines; again on the wet day cited above
- estimates at ground level from the rock outcrop at the northern end of the beach; these estimates were made simultaneously and independently by two observers standing at the same location; the estimates taken were on a dry day (15th August, 1983)
- observations along the profile lines; the observations were made simultaneously and independently by two observers; the observations were taken on the dry day

Table 5.4 Geochemical Analysis Results: Bay 11

	PROFILE	DATE	SHWR	ALK/ISO
(a) 1981	P3-U	20 Aug 81	2.5	2.6
	P3-M	20 Aug 81	2.4	2.7
	P3-L	20 Aug 81	2.9	2.8
	P6-U	20 Aug 81	2.8	2.7
	P6-M	20 Aug 81	2.4	2.8
	P6-L	20 Aug 81	2.5	2.7
	Mean all samples		2.6	2.7
	P3-U	15 Sept 81	1.2	1.8
	P3-M	15 Sept 81	1.9	2.8
	P3-L	15 Sept 81	1.5	2.8
	P6-U	15 Sept 81	1.5	2.9
	P6-M	15 Sept 81	1.6	2.7
	P6-L	15 Sept 81	1.8	2.7
	Mean all samples		1.6	2.6
(b) 1982	PI-U	08 Aug 82	1.0	1.0
	PI-M	08 Aug 82	1.2	1.1
	Pi-L	08 Aug 82	1.1	0.6
	P6-U	08 Aug 82	1.2	1.8
	P6-M	08 Aug 82	1.1	0.9
	P6-L	08 Aug 82	1.2	1.3
	Mean all samples		1.1	1.1
(C) 1983	Pi-u	16 Aug 83	1.0	1.0
	P 1-M	16 Aug 83	1.1	0.4
	Pi-L	16 Aug 83	1.1	0.2
	P3-U	16 Aug 83	1.6	2.5
	P3-M	16 Aug 83	1.0	0.7
	P3-L	16 Aug 83	1.2	0.4
	P6-U	16 Aug 83	1.7	1.9
	P6-M	16 Aug 83	1.7	2.1
	P6-L	16 Aug 83	1.1	0.3
	P8-U	16 Aug 83	1.1	1.4
	P8-M	16 Aug 83	1.1	1.4
	P8-L	16 Aug 83	1.1	0.3
	Mean all samples		1.2	1.1

The result of this series of observations and estimates is that the overall range, expressed as the per cent surface oil cover, is between 25 and 51%, or 26% (Table 5.5). If only the observations on the dry day, which were taken at approximately 180 locations along the 19 profile lines, are considered, the range is between 42 and 51%, or 9%. Taking the dry day observations as the more accurate of the two data sets, the fact that two observers produced a 9% difference suggests that data of this type should be considered within an accuracy range of +/-5%. Under relatively ideal conditions, on a dry day with two observers simultaneously and independently recording observations at exactly the same locations, a difference of 9% amounts to approximately a difference of 650 m^2 of the surface oil covering on a beach that is only 200 m in length and approximately 20 m in width. Thus, it is not possible to provide accurate data that can be used to compute oil budgets and such figures should be regarded as estimates rather than definitive values.

A breakdown of the observations recorded on both the dry and wet days indicates that observer 'A' was not consistent in the number of locations where there was no surface oil. The number of observations with no oil increased to 97 on the dry day from 88 on the wet day - a difference of 5% (Table 5.6). The difficulty in recording small quantities of oil on a pebble or cobble beach, when the surface of the individual sediments is wet, is an understandable source of variability. Observer 'A' showed greater consistency in the range of 1 to 24% and slightly overestimated those sites with greater than 50% oil cover; if it is assumed that the dry day observations are more accurate than those recorded on the wet day.

The comparison between the observations of 'A' and 'B' indicates that the latter recorded almost 80% of the observations in either the O or the 75 - 100% categories. This bias towards the ends of the scale resulted in relatively few values being recorded in the range of 1 to 50% (Table 5.6).

Table 5.5 Summary of Oil-cover Observations (expressed as % of surface with oil cover).

(a) Observations at 2-m intervals along 19 profile lines (dry day):

Observer A : 51%

Observer B : 42%

(b) Observations at 2-m intervals along 19 profile lines (wet day):

Observer A : 46% with oil

(c) Ground estimate from northern end of beach (dry day):

Observer A : 50%

Observer B : 45%

(d) Ground estimate from northern end of beach (wet day):

Observer A : 25%

(e) Aerial estimate on wet day:

Observer A : 35%

- sequence of estimates/observations:
  e, d, b, c, a

- range of estimates/observations:
  25 to 51%

The implications that must be drawn from this set of estimates and observations obtained in 1983 is that the information that has been obtained from surface oil cover surveys since 1981 is not sufficient to provide accurate results on the quantity of oil that remains on the shoreline. Assuming that the surveys in 1981 and 1.982 (which were conducted by a different observer, neither Observer 'A' or 'B') were undertaken at precisely the same locations and with the same objectives that were discussed by observers 'A' and 'B', then the estimates which have been produced to date are probably accurate to only $\pm5\%$.

The previous oil surveys of the intertidal zone indicate that the mean oil covering in August, 1981 was 58.5% and that this reduced to 36.9% in August, 1982 (Owens et al., 1983). The same value for August, 1983 is 19.3%, based on the dry day data from Observer 'A', a reduction of 17.6% between August, 1982 and August, 1983.

On the basis of the observations by 'A' on the dry day in August, 1983 the surface cover was 3,680 m^2; this compares to 9,560 m^2 for August, 1981 and 11,320 m^2 for August, 1982 (see Table 6.3 in Owens et al., 1983).

It is very apparent from both ground and aerial observations that the amount of oil that remains on the intertidal zone of Bay 11 in 1983 is considerably less than in 1982. The ground survey observations support this evaluation and the data obtained from the oil cover surveys is considered to be of sufficient accuracy to permit a general estimate of the total volume of oil that remains on this beach (see section 5.4.3, page 5-13).

A series of aerial photographs taken from approximately the same location in 1981, 1982 and 1983 indicate the changes in the visual appearance of the intertidal beach in Bay 11 (Fig. 5.2). The general view along Bay 11 in 1983 is given in Figure 5.3 to include the southern section of the beach which was largely oil-free in 1983. The summary diagram of the oil observations, taken by Observer 'A' on the dry day is presented in Figure 5.4. A comparison between visual conditions on the wet day and dry day is given in Figure 5.5.

Table 5.6 Comparison of Ground Observations of Oil Cover

Oil Cover (%)	Number of Recorded Observations		
	Dry Day		Wet Day
	Observer 'A'	Observer 'B'	Observer 'A'
0	88	105	97
1-24	37	20	34
25 - 49	28	4	16
50 - 74	14	14	16
75 - 100%	13	37	17

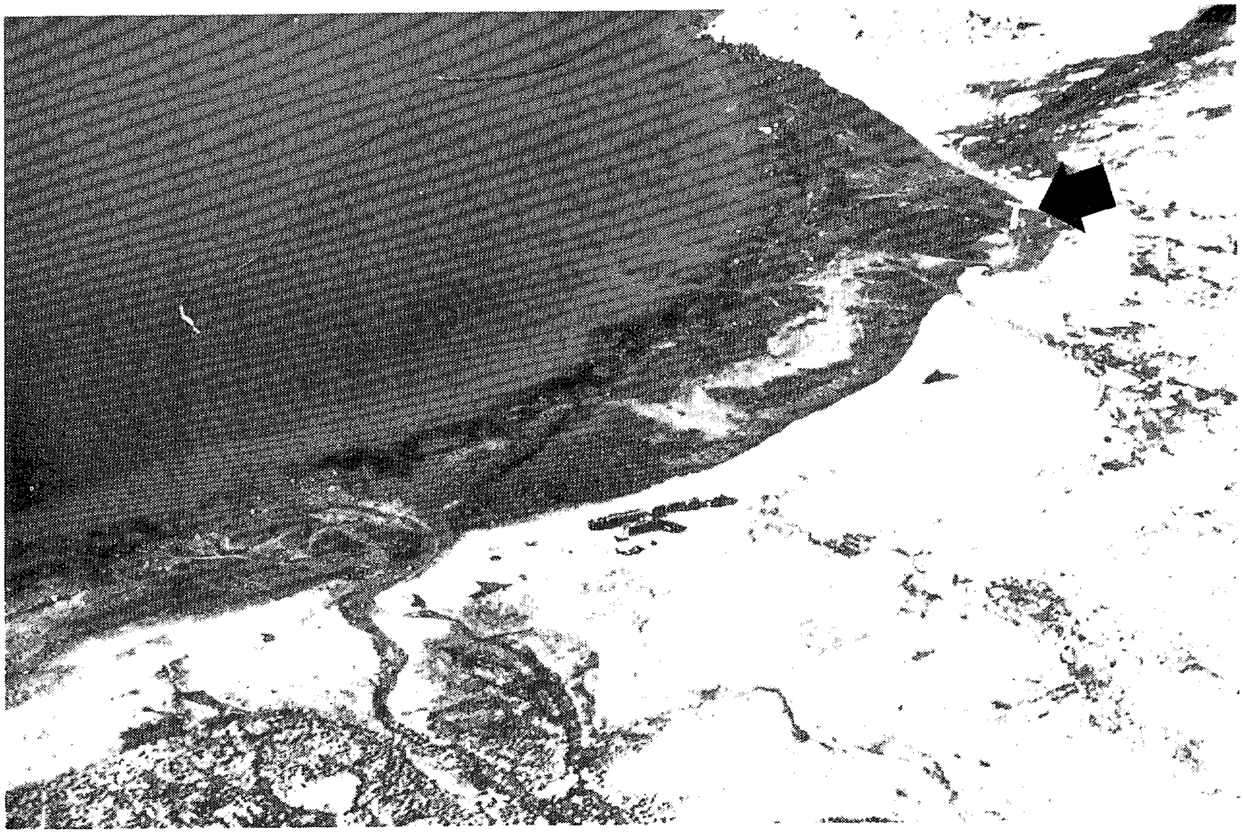
Evaluation of the surface oil cover observations between 1981, 1982 and 1983, produces some questions concerning the validity of comparisons. The length of the profile lines is significantly different between the 1981 and 1982 pair of surveys as compared to the 1983 surveys. In 1983 none of the survey profile lines was greater than 34 m in length, and only four were 30 m or longer; this compares to twelve lines that were 30 m or longer in the previous two surveys, and four lines that were longer than 50 m. The 1981 and 1982 surveys were conducted by using a cloth tape stretched over the profile line, whereas the 1983 surveys were conducted by pacing. The paced profiles obtained in 1983 were plotted at Cape Hatt and when the discrepancy was discovered the lines were subsequently checked by measuring selected profiles with a cloth tape. This checking procedure indicated that the paced profiles were accurate to within 5 m along the longest lines. No comparison is made between the previous surveys and the 1983 survey to avoid any errors that may be produced by comparison of non-compatible information.

Over much of the intertidal zone where oil was present the physical appearance was that of an asphalt material. In particular, an asphalt pavement had formed in the central section of the beach in the upper intertidal zone, where the oil-cover was greatest in 1983 (Fig. 5.4). Within this heavily oiled central section of the beach, the majority of the oil was concentrated along the beachface slope in the upper intertidal zone (Fig. 5.2c) and on the crest of a ridge in the lower one-third of the intertidal zone. On this section of the shore a trough of sand/silt sized sediments characterised the base of the beachface slope and separated it from the ridge. This trough was largely oil-free and usually the sediments were water-saturated. The ridge/trough system can be seen clearly in Figure 5.5a. The sediments of the ridge and the beachface slope are predominantly in the pebble and cobble size ranges. The asphalt pavement that was formed on the beach-face slope is discussed further in section 5.4.4 (page 5.19).

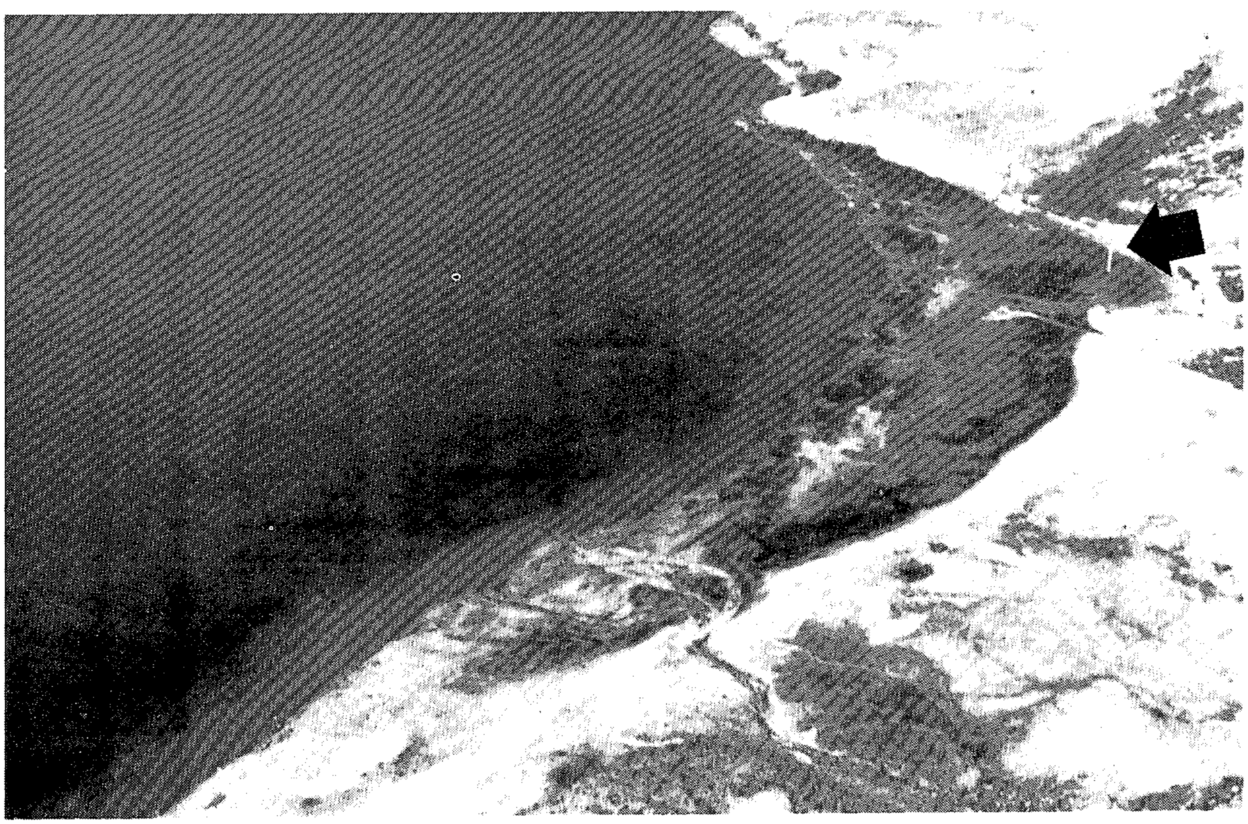
Samples for total hydrocarbon analysis were collected on the beachface, trough and ridge-crest areas. These were in addition to the samples indicated on Fig. 5.1. The two beachface samples had 27,000 and 2,800 mg/kg of oil in the surface sediments by weight, with subsurface values of 4,600 and 490 mg/kg. When this data is combined with the upper intertidal zone surface sample results (Table 5.2) the mean of all beachface surface samples is 19,835 mg/kg, with a maximum single value of 58,000 mg/kg. Surface samples from the ridge crest contained 9,700 and 550 mg/kg; and those from the trough 180, 470 and 810 mg/kg. Corresponding subsurface samples were 5,900 and 20 mg/kg on the ridge, and O, 0, and 28 mg/kg in the trough (see Fig. 5.8, page 5-23).

5.4.3 Estimates of Intertidal Oil Budget

Data provided by the Geochemistry Group of the BIOS Programme indicates that an estimated 5.6 m^3 of oil was stranded on the beach. To develop a budget of changes in the volume of oil on the beach, following the original spill, it has been assumed that the surface cover estimates obtained for each year provide a reasonable index of the total volume of oil on the beach. The average cover information that is used in Table 5.7 is



(a)



(b)

Figure 5.2 (a) Comparison of Bay 11 between 27th August, 1981, eight days after the oil was stranded, and

(b) 14th August, 1982. A small mast three metres high is indicated by the arrow near the right margin of both photographs.

(c)

Figure 5.2 (c) 14th August, 1983 (12:15). The mast had been removed by this time. All three photographs are at approximately 100 m altitude.

Figure 5.3 General view along the entire beach at Bay 11 (12:15, 14th August, 1983).

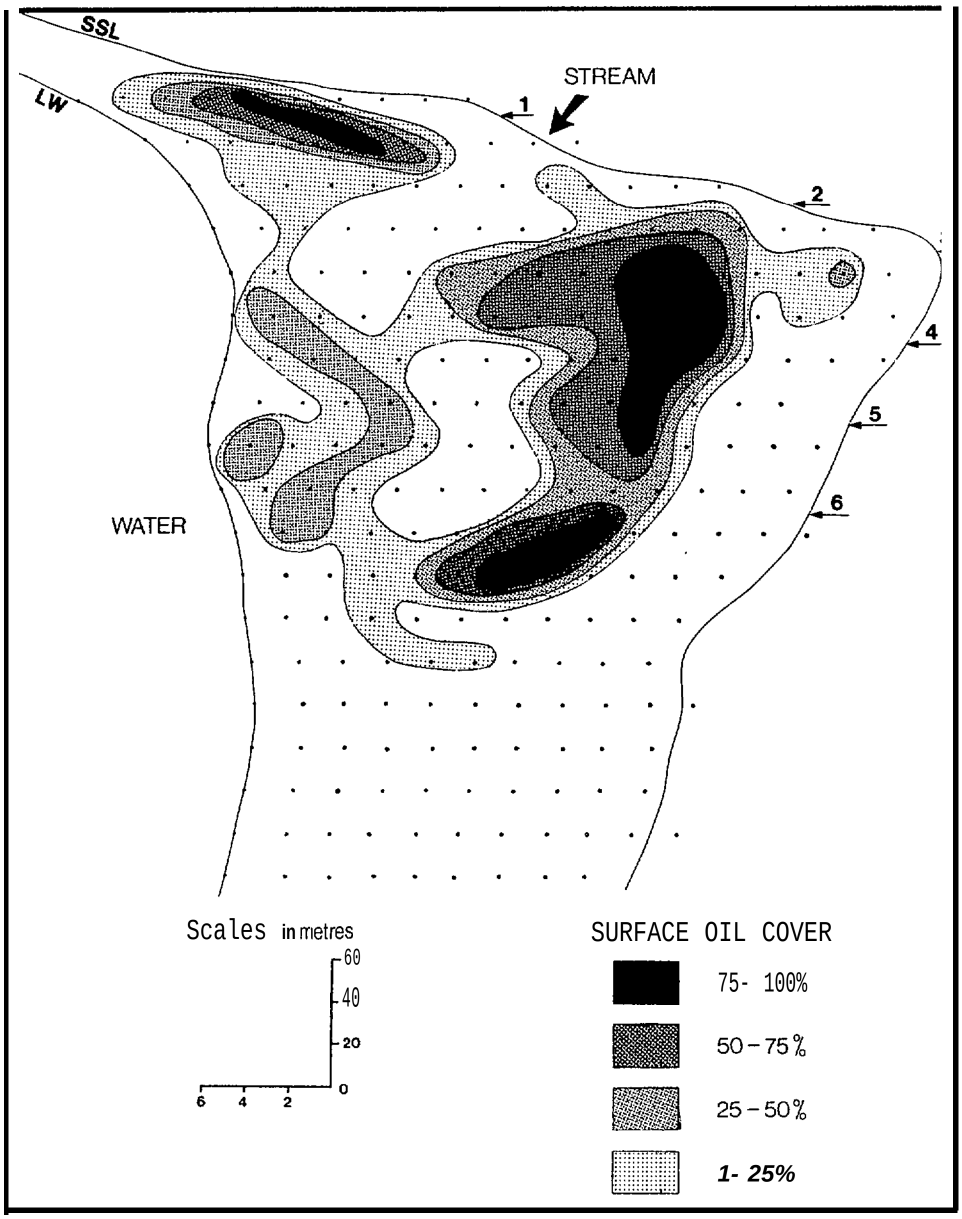
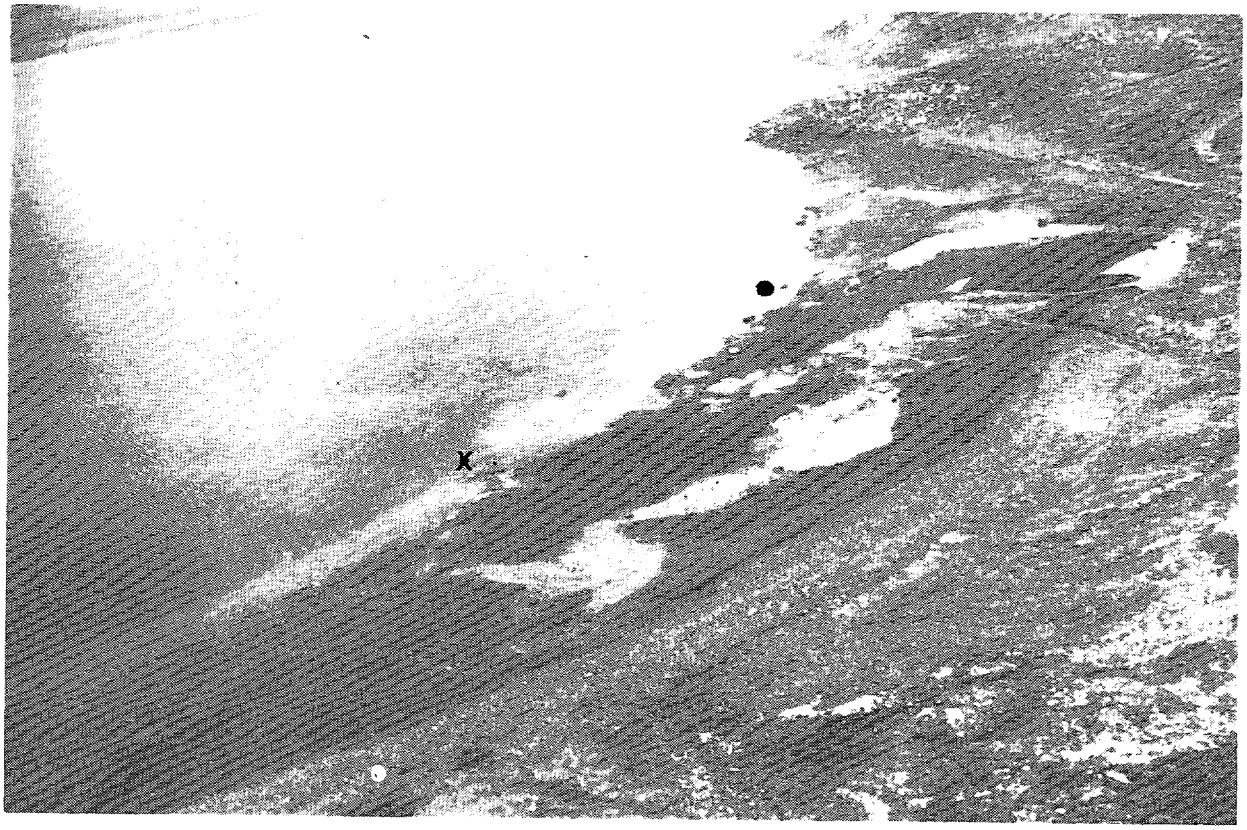


Figure 5.4 Summary of oil observations (by Observer 'A') on 15th August, 1983, a dry day: each dot represents an observation point. The scale has a width exaggeration of x 10 in order to provide across-beach details of the oil cover. The diagram has the same orientation as Figures 5.1 and 5.3. LW is the low-tide level on 15th August, 1983: SSL is the storm swash limit. The numbered arrows locate profile lines shown in Figure 5.1.



(a)

(b)

Figure 5.5 Comparison of the northern half of the Bay 11 intertidal zone on a:

(a) wet day - 12:05, 12th August, 1983; and
(b) dry day - 12:15, 14th August, 1983.

The cross and dots locate identical features on both photographs.

Table 5.7 Estimate Mass Balance for Oil Remaining on Bay 11 Intertidal Sediments

(a)

Year	Area Oiled (m^2)	Average Cover	Equivalent 100% Cover (m^2)	T	
1981	9,560	58.5%	5,593	5.6 m^3	100
1982	11,320	36.9	4,177	4.1 m^3	73
1983	3,680	19.3	710	see (c)	see (c)

(b) Asphalt pavement est. area = 470 m^2

Remaining equivalent area is therefore = 240 m^2

(c)

	1983 Equivalent 100% Cover (m^2)	Total Hydrocarbon (mg/kg)	Oil on Beach in 1983	z of Original
Asphalt pavement	470	20,000	1.9 m^3	34.0%
Remaining area	240	3,012	0.2	3.5%
Total	710		2.1 m^3	37.5X

derived from the surface cover maps that were made during each of the open-water seasons. On this basis, it is estimated that 73 per cent of the original volume of stranded oil was present at the time of the 1982 oil-cover survey (Table 5.7a).

In order to obtain estimates for the 1983 survey period it was necessary to differentiate between the asphalt pavement area and the remaining contaminated sections. This was necessary because of the high concentrations of oil within the asphalt pavement that were almost an order of magnitude greater than in the remaining contaminated areas. The approach taken for the 1983 estimate is one that includes both the spatial component of the surface-oil cover and the total hydrocarbon values for the asphalt pavement and the remaining areas. On this basis it is estimated that 37.5 per cent of the original volume of oil (or 2.1 m^3) was present in the inter-tidal zone at the time of the 1983 survey.

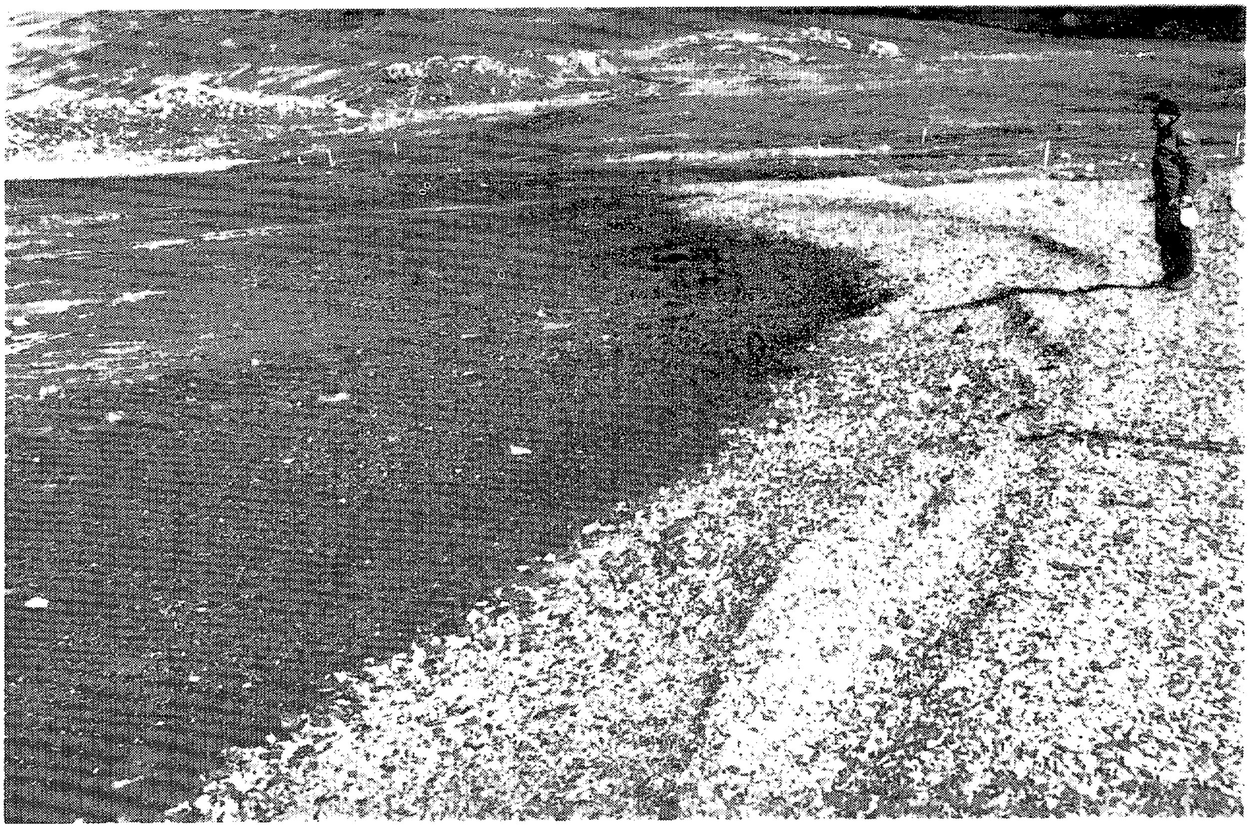
5.4.4 Asphalt Pavement

The field investigations in 1983 indicate that an asphalt pavement had formed between Profiles 2 and 6 (Fig. 5.4) since the previous set of observations in August, 1982. The most striking component of the asphalt pavement was the presence of a distinct upper edge, approximately 1.5 to 2 m below the mean high-water level.

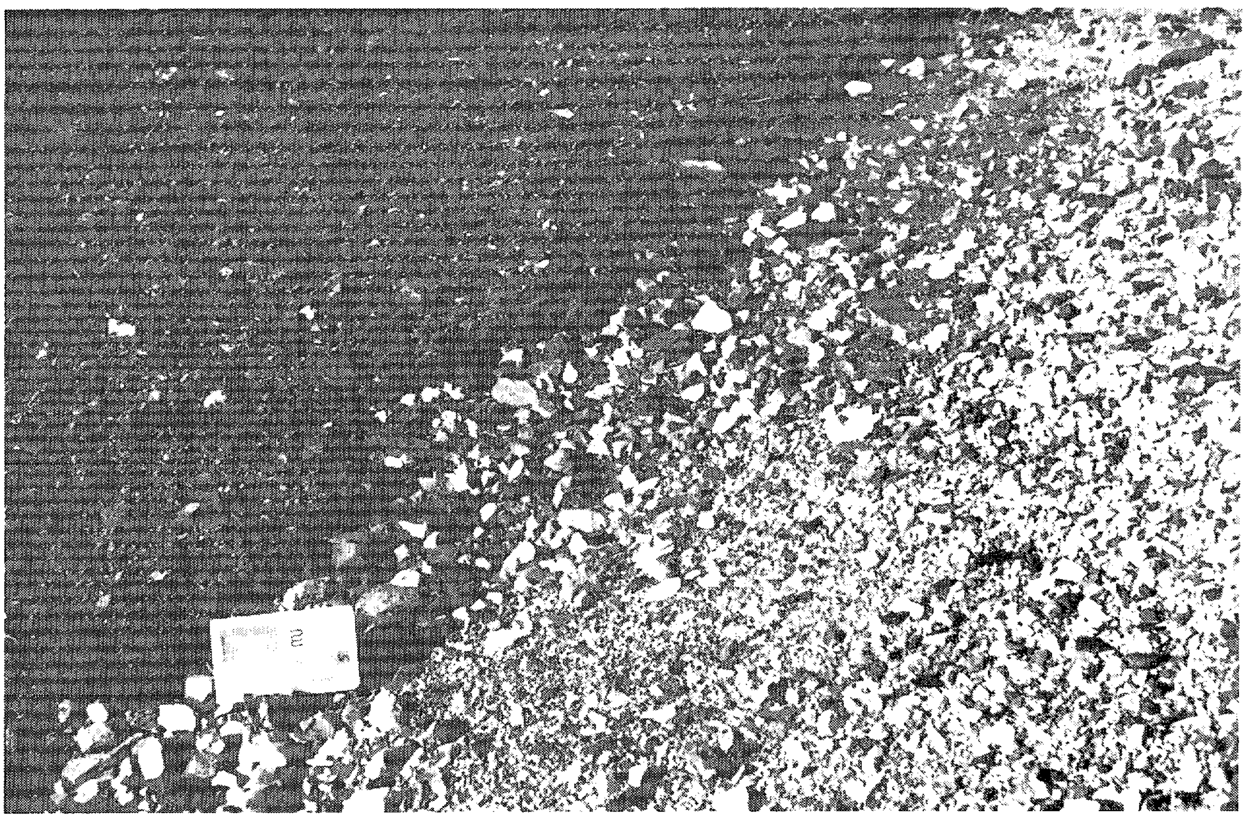
The pavement varied in width from a minimum of 2 to a maximum of 5 m and extended for a total length of approximately 150 m alongshore. The surface of the asphalt pavement was very smooth and very firm. The total hydrocarbon values obtained from samples collected in the surface of the asphalt pavement produced values that ranged between 27,000 and 58,000 mg/kg. By comparison the highest total hydrocarbon value obtained outside of the asphalt pavement area was a single point of 14,000 mg/kg, and sub-surface samples below the asphalt pavement were in the order of 500 to 1,500 mg/kg (Table 5.2)..

Little information is available in the literature on asphalt pavements and their formation. Samples collected following the 'Arrow' spill in Chedabucto Bay in 1970 on an asphalt pavement at Arichat, Nova Scotia, produced values of 40,000 and 50,000 mg/kg (Owens, 1971). That asphalt pavement was subsequently removed by heavy equipment so no further data is available from that site. Visual observations at Black Duck Cove, Nova Scotia, and at Crichton Island, Nova Scotia, three years after the same event indicate the presence of asphalt pavements, but no additional information was obtained (Owens, 1978).

A large asphalt pavement was formed following the 'Metula' spill in the Strait of Magellan, Chile. Figure 5.7 illustrates some of the aerial and ground characteristics of the pavement that was formed in the vicinity of the Puerto Espora at the First Narrows. The spill occurred in August, 1974 and the photographs presented in Figure 5.7 were taken 2½ years later in January, 1977. Further observations by Gundlach et al., (1982) in February, 1981, 6½ years after the event, indicate that an asphalt pavement approximately 15 cm thick and between 20 and 40 m wide was still present at this site. Gundlach, et al., 1982 present photographs that are comparable with Figure 5.7b.



(a)

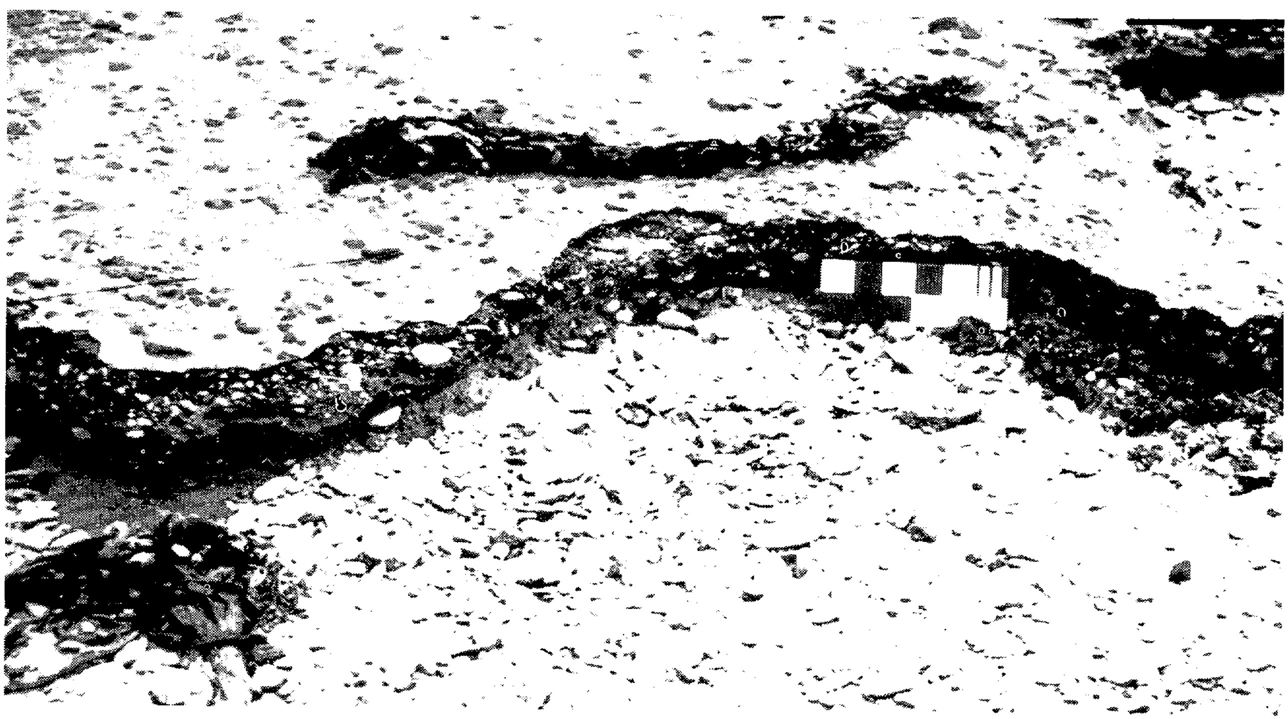


(b)

Figure 5.6 (a) Ground view along the beach at Profile 6: this is an area with the highest surface oil cover (14th August, 1983).

(b) Close-up of the upper edge of the asphalt pavement near Profile 4: the note book is 20 cm in length (13th August, 1983).

(a)



(b)

Figure 5.7 Photographs of an asphalt pavement taken in January, 1977, 2½ years after the 'Metula' spill in the Straits of Magellan, Chile, at Puerto Espora.

(a) Ground view (cf. Figure 5D in Gundlach, et al., 1982)

(b) Close-up of upper edge of asphalt pavement (scale is 30 cm in length).

unfortunately there is little or no information on other asphalt pavements even though it is apparent that these are a common occurrence in environments characterised by cold climates, weathered or heavy oils, and gravel or coarse-grained beaches.

5.4.5 Discussion

The contaminated intertidal sediments of the Bay 11 beach are an important source of hydrocarbons that are leaching into the adjacent near-shore waters. A significant proportion of the leached hydrocarbons migrate into the subtidal sediments. Data obtained along the microbiology transect, adjacent to Profile 6, indicates that there has been a six-fold increase in sediment concentrations from samples collected during 1983 when compared to those analysed from 1982 (Boehm, 1984). In the subtidal sediments immediatley adjacent to the low-water line, the total hydrocarbon values, at 2 and 3 m depths respectively, are 87 and 45 mg/kg. The highest concentrations are at 10 and 25 m from the low-water line, in water depths of approximately 2.5 m, with values of 410 and 120 mg/kg respectively. Between 35 and 65 m offshore the values range from 29 to 45 mg/kg and between 65 and 145 m, which is an area of water depths between 3 and 10 m, the values are in the order of 0.8 to 4.5 mg/kg. The substantial increase in the total hydrocarbon concentrations in the sediments between 1982 and 1983 reflects the rate of removal of oil from the intertidal zone (Table 5.7). It is likely that leaching will continue subsequent to 1983 but that the rate at which hydrocarbons will be removed from the intertidal zone will decrease. Much of the oil that remains in the intertidal zone in a relatively stable form as the majority of these hydrocarbons are tied up in the asphalt pavement.

The distribution of oil in the intertidal zone of the Bay 11 beach reflects the relationship between the sediments and the morphology of that beach. In the central section of the bay the ridge in the lower one-third of the intertidal zone, which is an incipient boulder barricade, has a contamination level of approximately 1 per cent in 1983 (Fig. 5.8). The total hydrocarbon values in the trough are generally less than 0.1 per cent and the majority of the oil that remains on the shoreline is in the asphalt pavement that has formed on the beach-face slope. The total hydrocarbon values on the asphalt pavement are in the order of 2 to 5 per cent and these concentrations are similar to those that have been recorded in real oil-spill situations. The information and data that are being obtained from the Bay 11 spill are extremely valuable because of the similarity between this experiment and observations that have been made at actual spill incidents.

An important characteristic of the Bay 11 intertidal zone in 1983 is that the clean-up of the remaining oil would be considerably easier when compared to either the 1981 post-spill conditions or the 1982 situation. In the lower intertidal zone the ridge still contains some hydrocarbons but these concentrations are very low and it is unlikely that this section of the intertidal zone would require clean-up. The majority of the oil in 1983 is contained in the asphalt pavement and removal of this by either manual or mechanical methods would be a relatively simple process, and would not involve large-scale sediment removal.

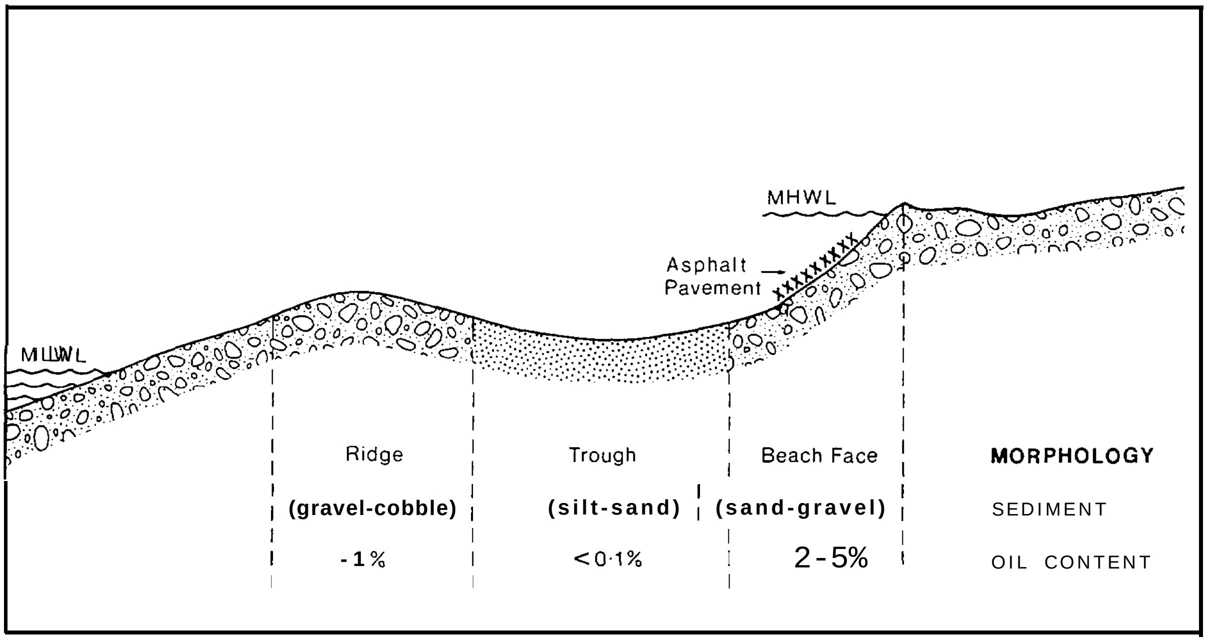


Figure 5.8 Schematic diagram of the relationship between oil concentrations (expressed as per cent oil-in-sediment by weight), sediment type and morphology along a profile line across the intertidal zone in Bay 11 (cf. Profile 5 on page A-12 in Owens, et al., 1983).

The variability in the oil-cover that was recorded by the estimates and observations, under different environmental conditions and by different observers, is an important parameter in evaluating the degree of contamination for real-world spill conditions. Within this small study area (7,200 m^2) the same observer provided estimates of the surface oil-cover that ranged from 1,800 to 3,680 m^2. This wide variability for a small section of shoreline would probably be magnified during reconnaissance surveys when long sections of coast are surveyed to determine the degree of contamination. This variability has serious implications if the data is to be used for the development of beach clean-up decisions or for the assessment of damage potential. Large under-estimates or over-estimates of the volume of oil remaining on a beach can lead to errors in evaluating the cost of a clean-up programme or the length of time that might be required to treat the shorezone. Accuracy is a function of both the level of effort as well as the environmental conditions. The choice of method of survey for a contaminated area would depend upon the ultimate use of the data. On dry days a single, careful ground estimate may be consideralby less time consuming, yet may be within the same accuracy range as a detailed intertidal survey.

Published data from the 'Amoco Cadiz' indicates that six weeks after the spill 393 km of shoreline were contaminated (Ness, 1978). Calculations based on the length of contaminated shoreline and the degree of oiling produced a value of 11,080 metric tons of oil present along the shoreline (Table 5.8a). Assuming that the degree of accuracy obtained by the survey that yielded this information was in the same range as the detailed observations in Bay 11 on the dry day by observers walking along profiles, it would be valid to apply a ±5 per cent factor to these values (Table 5.8b). If a lower level of accuracy is considered, similar to some of the variability that was found by the different surveys conducted in Bay 11, and a ±13 per cent factor is used then the potential variability in estimating the length of contaminated shoreline and evaluating the amount of oil that remains in the shoreline becomes significant for operational decisions (Table 5.8c).

Table 5.8 Possible Variability in Estimated Contamination following the 'Amoco Cadiz' Spill

(a) Published Estimates of Contamination 6 Weeks after the Incident (from Ness, 1978)		
length of coast oiled	393 km	
estimated amount of oil on the coast	11,080 metric tons	
(b) Variability with assumed +/-5% accuracy		
length of coast oiled	373 - 413	(40 km)
estimated amount of oil on the coast	10,526 - 11,634	(1,108 t)
(c) Variability with assumed +/-13% accuracy		
length of coast oiled	342 - 444	(102 km)
estimated amount of oil on the coast	9,640 - 12,520	(2,880 t)

Estimates of the amount of oil that contaminated the shoreline following the 'Metula' spill in the Strait of Magellan by different observers illustrate the difficulties of obtaining accurate estimates of the volume of stranded oil in real-spill situations. Along a heavily-oiled beach section one observer estimated that 60,000 m^2 of emulsion were present in that area (Gunnerson and Peter, 1976). A few weeks later another estimate obtained by a different set of observers in the same area measured approximately 45,000 m^2 of emulsion,

The Bay 11 study is a very important component of the overall shoreline investigations. This beach provides a dataset against which the experiments that were conducted in Z-Lagoon can be compared. The fact that the characteristics of the contaminated intertidal zone are similar to situations that have been observed in real spill incidents makes this beach of particular value.

5.5 SUMMARY

The field programme on the beaches of Ragged Channel was directed towards an evaluation of the long-term fate of oil stranded in the intertidal zone. In particular, Bay 11 is an important experimental site as it represents a rare opportunity to monitor the fate of a relatively large volume of stranded oil at a location where *it* will be possible to continue the observations over a long-term period. The primary observations that result from the 1983 field programme are:

- the intertidal sediments of Bay 9 remain oil-free, only very low concentrations of hydrocarbons can be detected

- the intertidal sediments of Bay 11 continue to be cleaned by natural littoral processes; in particular, the intertidal sections at the north and south ends of the beach show significant decreases in total hydrocarbon concentrations; the central upper intertidal zone section shows an increase in total hydrocarbon values due to a redistribution of contaminated sediments up the beach by littoral processes

- on those sections where a 100% oil-cover was observed (the asphalt pavement areas) the maximum single total hydrocarbon value of the surface sediment samples was 58,000 mg/kg (5.8%)

- the intertidal oil-cover in Bay 11 is approximately 3,680 m^2, out of a total area of 7,200 m^2

- the oil that remains is concentrated in the upper intertidal zone on the beachface slope and on a pebble/cobble ridge in the lower intertidal zone in the central section of the Bay 11 shoreline; the ridge and beachface slope are characterised by coarse sediments and are separated by a trough of sand/silt sediments, which are relatively free of oil

- the mean total hydrocarbon values for all beachface slope samples is 19,835 mg/kg; for the trough samples is 486 mg/kg; and for the ridge crest samples is 5,125 mg/kg: if the data is considered in terms of the location of the oil and the intertidal topography, the beach-face slope that has an asphalt pavement has oil concentrations in the range of 20,000 to 60,000 mg/kg (2 to 6%); the ridge has concentrations up to 10,000 mg/kg (1%) and the trough has concentrations that are below 1,000 mg/kg (0.1%). These concentrations are similar to values obtained from actual spill incidents

- the accuracy of the oil-cover survey is sufficient to provide only estimates of the volume of oil remaining in the intertidal zone; the volume of oil remaining in August, 1983 is in the order of 2.0 m^3, or about one-third of the original volume that was stranded in August, 1981

- comparison of several oil cover surveys indicates that there exists significant variability (a) between two observers recording simultaneously and independently, and (b) between a single observer on dry and wet days; the oil-cover estimates range between 25 and 50%

- oil observations and estimates of the surface oil cover obtained on a wet day were significantly lower than those obtained on a dry day

- oil continues to leach out of the beach area into the adjacent nearshore environment and is likely to continue to do so, but at slower rates than in the period up to August, 1983

6.1 RESULTS FROM THE 1983 PROGRAMME

Specific conclusions that have been reached with regard to individual experiments are summarised at the end of each section in this report. This summary highlights some of the major conclusions that have been reached from the 1983 programme and focuses on the general objectives of the study rather than the individual results.

Previous assessments of the results of the countermeasures experiments (Owens et al., 1983) suggested that mixing by rototiller in the backshore environment promoted reduction of surface hydrocarbons. After one year at the Bay 106 site it is evident that the mixing procedures have resulted in a significant reduction of hydrocarbons in the surface sediments, but that the method causes an increase in the concentrations of hydrocarbons in the subsurface sediments.

On the intertidal plots in Bay 106 it has become apparent that the natural processes of oil removal by water action have been effective in reducing the oil content of the surface sediments. One year after the oil was laid down and the experiments were conducted it would appear that the natural processes of oil removal are as effective as the shoreline countermeasures that were tested in this fine-grained, low-energy environment. The general conclusion that can be reached on the Bay 106 experiments is that for the type and volume of oil that was laid down on the intertidal zone the use of dispersants did not prove to be very effective in terms of cleaning the contaminated sediments, and that natural processes, although slow, appear to be effective over the period to date. On the backshore the use of mixing by mechanical methods reduces the total hydrocarbon concentrations in the surface sediments, but increases the subsurface hydrocarbon contents.

The study beach in Bay 106 is significantly different from the intertidal control plots (L-1 and L-2) in terms of the beach sediments. On Bay 106 the fine-grained materials are more densely packed and have a higher water content so that little oil penetrated below the surface layer. As a result of this difference in the sedimentological characteristics of the beach, the rate of natural cleaning of the Bay 106 plots is greater than the rate recorded for the crude oil plot (L-l). By comparison with the counter-measure plots at Crude Oil Point, the natural recovery of the Bay 106 beach is considerably slower. The residence time of oil in the intertidal zone is a function not only of the levels of mechanical wave energy at the shoreline but also of the sediment type and character.

A reduction in the surface and subsurface total hydrocarbon values on the backshore crude oil control plot (T-1) and also in the subsurface of the emulsion plot (T-2) cannot be explained on the basis of the existing data set. Although Humphrey (1984) cautions against the comparison of results which are within one order of magnitude of each other, the reduction of the oil volumes from between 63% and 88% to between 22% and 41% requires clarification.

Natural cleaning of the contaminated intertidal sediments on Bay 11 continues to be evident from the surface oil cover and from the total hydrocarbon sample results. There has been a redistribution of the contaminated sediments so that some sections of the shore, particularly at the northern and southern ends of the beach, and in the lower intertidal zone, have become clean whereas there has been a concentration of oiled material on the upper intertidal zone in the central section. An asphalt pavement has formed in the central upper intertidal zone and in this region total hydrocarbon concentrations remain very high; up to 6% oil-in-sediment by weight. Repetitive surveys of the surface oil-cover indicate the variability that can exist from estimates obtained by different observers, on wet and dry days, and from the ground and from the air. The results of these surveys indicate the great caution that must be taken when utilising both cursory estimates as well as detailed observations along profile lines.

There exists no method by which the volume of oil remaining in the intertidal zone can be determined accurately, but estimates in the order of ±5% are possible. Bay 11 remains a very important study site for assessment of the long-term fate of oil stranded on intertidal beaches in an arctic environment and for the study of an asphalt pavement.

6.2 RESULTS OF THE PROGRAMME 1980 TO 1983

6.2.1 Introduction

The results of the shoreline component of the BIOS Programme will be synthesized in a series of published papers. These results will be derived from the data and information that is contained in this and previous Working Reports. This section summarises the results of the Programme using as a framework the same basic topics developed for the final papers. At this stage it is intended only to highlight the major results and conclusions.

6.2.2 The Deposition and Persistence of Oil on the Test Beach Plots

The experiments that were conducted in the vicinity of Z-Lagoon involved the application of oil to pairs of control plots in the upper intertidal zone on four beaches and on backshore control plots at two locations. Each of the intertidal sites is characterised by a different exposure to wave conditions. The backshore plots were established above the normal limit of marine processes.

At each location one plot was oiled with an aged Lago Medio crude and the other with a water-in-aged crude oil emulsion. Oil retention on the intertidal emulsion plots was considerably less than the aged oil; probably as a result of the poor adhesion properties of the emulsified oil.

At the exposed site, in Bay 102, more than 99 per cent of the oil that was applied to the plots was removed from the surface within 48 hours. This removal took place due to the mechanical energy of wave action and to the redistribution of sediments by those waves. In the more sheltered locations (Bays 103 and 106), wave processes were not significant in removing the applied oil. At these sites the rising water level was the primary agent in oil removal following the application of either the crude or the emulsion to the control plots. In Bay 103, 70 per cent of the oil on the crude plot and more than 90 per cent of the emulsion were removed within 48 hours as a result of the rising water levels alone. The same information for the Bay 106 intertidal plots is 90 per cent on the crude plot and 30 per cent for the emulsion plot. The amount of oil that is retained on an intertidal surface is a function of:

- the size of the sediments
- the size of the interstitial spaces of the surface sediments
- the surface properties of the sediments (including texture and wetness/dryness)
- the level of the water-table with respect to the beach morphology, and
- the type and volume of the oil

The fate and persistence of the stranded oil is a function of not only the wave-energy levels at the shoreline but also of the regional climate, the oil loading, the characteristics of the sediment, beach topography and the formation of an asphalt pavement. All of these factors must be considered when evaluating the persistence of oil on either the Z-Lagoon control plots or the Bay 11 experimental beach.

The data from the intertidal test plots has a limited value as much of the oil was redistributed to adjacent uncontaminated areas. By contrast, at the Bay 11 experimental site a large volume of oil covered the entire intertidal zone over much of that beach. In this latter instance one therefore has data that more truly represents real oil-spill situations in terms of the fate and persistence of the oil that was stranded on that shore. The data from the testplots is nevertheless valid in the short-term as the mean values and the range of values of the total hydrocarbon samples collected from the crude oil plots immediately after distribution of the oil are in the same general range as the total hydrocarbon samples that were taken from Bay 11. This indicates that the experimental plots were reasonable replicates of real oil-contaminated beach areas over the short-term. The plots become less representative as the oil is redistributed to uncontaminated adjacent sections of beach. It is therefore reasonable to accept the results associated with the experimental plots during the first open-water season, that is up to approximately six weeks. By the time of the second open-water season, the oil on both the control and experimental plots would have become redistributed to a degree that would make the results less comparable to sites such as the Bay 11 shoreline.

6.2.3 The Fate and Persistence of Oil Stranded on the Bay 11 Shoreline

Immediately following release of the oil and contamination of the intertidal zone the oil concentrations were highest on the beach-face slope in the upper intertidal zone, and on the crest of a ridge in the lower section of the intertidal zone. Both of these areas are characterised by coarse (pebble/cobble) sediments. This initial pattern remained the primary feature of the contamination through all three open-water seasons of this Programme. The actual total hydrocarbon values obtained from sample analyses were extremely variable due to the high variability of the surface oil distribution, in terms of both area and thickness.

The area of contamination of the surface sediment was reduced from approximately 9,000 m^2 to 3,500 m^2 between 1981 and 1983, i.e. two complete open-water seasons. The average concentrations of total hydrocarbon values over the entire beach decreased from 5,900 mg/kg in 1981 to 4,374 mg/kg in 1982. However, there was an increase in this value to 9,442 mg/kg in 1983 due to the concentration of the remaining oil within the asphalt pavement. The mean value for the samples collected from the asphalt pavement on the beach-face slope in the upper intertidal zone was in the order of 20,000 mg/kg in 1983.

Observations on the surface oil-cover during each of the three study seasons indicate the difficulties that exist in providing accurate estimates of either the amount of oil that remains on a shoreline or the actual area of contaminated shoreline. In one series of tests the estimated surface area that was contaminated ranged between 25 and 51 per cent. This variability is affected by the type of survey, aerial versus ground or detailed versus reconnaissance, and by environmental factors, wet versus dry conditions. The best estimates were obtained by observation from the ground on a dry day. The worst estimates, which were 50 per cent lower than *the* dry-day ground estimates, were obtained from the air on a wet day. This high degree of variability is very important if accurate estimates are required for damage assessment of a shoreline following a spill or for the development of clean-up decisions.

From the data set it is clear that the intertidal sediments have been and continue to be cleaned by natural littoral processes. This occurs despite the fact that this is a relatively sheltered wave-energy environment in *an arctic* location and that approximately four months of open-water conditions only have elapsed between the spill and the 1983 observations set. Although the intertidal sediments continue to be cleaned naturally, the rate of this cleaning will probably become slower after 1983 as much of the oil that could be easily removed has been removed and the remaining oil is consolidated in the form of an asphalt pavement.

6.2.4 An Evaluation of Selected Beach Cleanup Techniques for Arctic Environments

The results that have been reported as part of this project must be considered in terms of other clean-up techniques that are available for Arctic shorelines. This study purposely did not consider techniques that had been tested or evaluated in previous studies in lower latitudes. Any evaluation of a clean-up technique involves determining the value of implementing a particular operation to reduce oil concentrations. Factors that must be considered for each circumstance include the availability of equipment, logistic requirements, the cost and the potential adverse effects of the clean-up activity. This series of experiments was designed to provide data that would make such evaluations more realistic. The objective of each experiment was not to clean the test-beach plots but rather to focus on an evaluation of the effectiveness of the individual technique. The selected techniques were evaluated and assessed with respect to the control plots, not to each other.

Two commercial dispersants were applied to oiled intertidal plots in the vicinity of Crude Oil Point. Over a period of a few days following the experiments, the total hydrocarbon concentrations on the plots were considerably reduced; within several weeks the total hydrocarbon values on the control and on the dispersant plots were not significantly different. At first sight it would appear that the reduction in oil concentrations on the dispersed plots was effective. After eight days the concentrations were in the range of 20 to 2,300 mg/kg as compared to values between 17,000 and 21,700 mg/kg on the adjacent control plots. When the same experiments were repeated in the more sheltered location the dispersants proved to be considerably less effective even though one of them was applied using a fire-hose that imparted considerable physical energy to the dispersant application. From a practical viewpoint, dispersants could be used on small sections of shoreline, for example in the order of tens of metres, on open coasts which are affected by wave activity. The use of dispersants would be applicable if the stranded oil would otherwise have a severe negative impact and if movement of the dispersed oil into the adjacent nearshore waters would be acceptable. The procedure is however slow and expensive, and in the long run may be no better than natural cleaning if there exists sufficient wave activity to remove the oil naturally. One particular application of dispersant use might be to prevent the formation of asphalt pavements in the intertidal zone. On the Bay 11 shoreline this type of solid feature formed after two open-water seasons. The use of dispersants would probably have prevented this development if those dispersants had been applied to remove much of the stranded oil during the first open-water season.

Mechanical mixing on the intertidal plots resulted in the reduction of total hydrocarbon concentrations in the surface sediments. Oil was pushed deeper into the beach and this delayed rather than accelerated the natural cleaning of those plots. On the backshore plots in Bay 106 the mixing procedures again reduced total hydrocarbon values of the surface sediments but oil was driven into the subsurface. The value of this technique can be to prevent or reverse the formation of an asphalt pavement in the intertidal zone. Apart from this application, the technique does not appear to offer any major advantages over natural cleaning. In the backshore environment the technique can reduce surface total hydrocarbon concentrations and therefore create a more acceptable surface in terms of surface traffic contamination. The procedure is a comparatively low-cost and low-labour intensive method which requires a relatively simple logistic operation. The technique is one therefore that can be used on accessible beaches and large areas can be mixed rapidly using mechanical equipment.

One small experiment was conducted with a low-pressure hose on the fine-grained beach in Bay 106. The experiment indicated that total hydrocarbon concentrations were not reduced by this method. The technique is a labour-intensive operation and it is unlikely that it would have a significant application to arctic environments.

A solidified was used during the 1981 experiments and proved to be an effective method to encapsulate the oil. The method that was used was one that would be labour-intensive and expensive using presently available materials. The solidified oil appeared to be resistent to wave processes and lumps of the solidified oil-sediment mixture were still present on the shoreline during the third open-water season.

A series of small burning tests were conducted prior to the 1981 experiments and the igniters that were deployed were unable to initiate combustion on the test plots. This method is considered to have little or no applicability as a clean-up option.

The results and conclusions briefly described above must be considered in t'ne context of all available options. The particular value of this series of experiments is that actual data is now available by which the techniques can be compared to control plots set up at adjacent locations. Only by this type of carefully controlled experiment in which comparable data-sets are collected can effective planning decisions be developed. When one considers the amount of research that has been conducted on oil-spills and on spill-response methods over the past decade there is surprisingly little data available that deals with the effectiveness or efficiency of shoreline clean-up methods.

6.2.5 Recommended Further Studies

The information and data that has been collected from the Bay 11 shoreline has provided a valuable insight into the fate and persistence of stranded oil. The results are applicable not only to this environment but may be applied more generally to other areas including low-latitude locations with a similar environmental setting, that is in terms of the wave-energy levels and the shoreline characteristics. Further investigations at this location in future years would be highly desirable to provide a longer term data-set. It is recommended that the observations and analyses be conducted in future years with an emphasis on the total hydrocarbon and the analytical geochemical aspects of the study.

If future studies are conducted in Bay 11 it is recommended that observations be undertaken and samples collected on the backshore plots in Bay 106. This information would provide longer-term data on the merit of undertaking mixing of oils that might be stranded above the normal limit of wave activity.

Little is known about the formation or the physical and chemical characteristics of an asphalt pavement. The data that has been collected from the Bay 11 site to date provides a basis from which it would be possible to make comparisons with other similar situations. For example, asphalt pavements are known to have formed following the 'Arrow' spill in Chedabucto Bay in 1970 and the 'Metula' spill in the Straits of Magellan in 1974. It is recommended that a programme be developed to investigate these and other asphalt pavements that might exist in order to provide a scientific evaluation of the character and persistence of this type of contamination.

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Table A.1 Results of Analyses from Samples Collected during 1983 from the 1980 Control Plots

SAMPLE NO.	PLOT	LOCATION	DATE	t-h (mg/kg)
S4001	H1	surface	83-08-20	DL
.s4002	H1	subsurface	83-08-20	DL
S4003	H2	surface	83-08-20	DL
S4004	H2	subsurface	83-08-20	DL
S4005	L1	upper surface	83-08-20	1200
s4006	L1	upper subsurface	83-08-20	23000
S4007	L1	middle surface	83-08-20	28o
s4008	L1	middle subsurface	83-08-20	1900
S4009	L1	lower surface	83-08-20	400
S401O	L1	lower subsurface	83-08-20	730
S4011	L2	upper surface	83-08-20	20
S4012	L2	upper subsurface	83-08-20	DL
S4013	L2	middle surface	83-08-20	DL
S4014	L2	middle subsurface	83-08-20	DL
S4015	L2	lower surface	83-08-20	DL
S4016	L2	lower subsurface	83-08-20	DL
S4017	T1	surface	83-08-20	10000
s4018	T1	subsurface	83-08-20	6700
S4019	T1	surface	83-08-20	8700
S4020	T1	subsurface	83-08-20	8700
S4021	T1	surface	83-08-20	64oo
S4022	T1	subsurface	83-08-20	9500
S4023	T1	surface	83-08-20	10000
S4024	T1	subsurface	83-08-20	13000
S4027	T2	surface	83-08-20	21000
S4028	T2	subsurface	83-08-20	84oo
S4029	T2	surface	83-08-20	24000
S4030	T2	subsurface	83-08-20	10000
S4031	T2	surface	83-08-20	28000
S4032	T2	subsurface	83-08-20	4700
.s4033	T2	surface	83-08-20	17000
S4034	T2	subsurface	83-08-20	570

Additional samples:

S4921	L1	high water mark - surface	83-08-20	1500
S4922	L1	high water mark - subsurface	83-08-20	1100
S4923	H1	oil patch	83-08-17	1300

Table A.2 Results of Analyses from Samples Collected during 1983 from 1981 Countermeasure Experiments and Control Plots

SAMPLE NO.	PLOT	LOCATION	DATE	t-h (mg/kg)
S4101	CC	surface	83-08-20	22
S4102	CC	subsurface	83-08-20	430
S4103	CE	surface	83-08-20	21
S4104	CE	subsurface	83-08-20	190
S4105	MC	surface	83-08-20	32
s4106	MC	subsurface	83-08-20	3200
S4107	ME	surface	83-08-20	20
S4108	ME	subsurface	83-08-20	84
S4109	D(B)C	surface	83-08-20	DL
S4110	D(B)C	subsurface	83-08-20	DL
S4111	D(B)E	surface	83-08-20	DL
s4112	D(B)E	subsurface	83-08-20	DL
S4113	D(E)C	surface	83-08-20	20
S4114	D(E)C	subsurface	83-08-20	20
S4115	D(E)E	surface	83-08.20	DL
S4116	D(E)E	subsurface	83-08-20	120

Additional Samples (located on Figure 3.2):

S4925	1	surface	83-08-20	88
S4926	1	subsurface	83-08-20	110
S4927	2	surface	83-08-20	440
s4928	2	subsurface	83-08-20	170
S4929	3	surface	83-08-20	1200
S4930	3	subsurface	83-08-20	110
S4931	4	surface	83-08-20	680
S4932	4	subsurface	83-08-20	210

Table A.3 Results of Analyses from Samples Collected in 1983 from 1982 Intertidal Experimental and Control Plots

SAMPLE NO.	PLOT	LOCATION		DATE	t-h (mg/kg)
S4231	ID(E)E	1	surface	83-08-20	98
S4232	ID(E)E	1	subsurface	83-08-20	DL
S4233	ID(E)E	2	surface	83-08-20	6400
S4234	ID(E)E	2	subsurface	83-08-20	86
S4235	ID(E)E	3	surface	83-08-20	410
s4236	ID(E)E	3	subsurface	83-08-20	DL
S4237	ID(E)E	4	surface	83-08-20	310
s4238	ID(E)E	4	subsurface	83-08-20	DL
S4239	ID(E)E	plot	surface	83-08-20	49
S4240	ID(E)E	plot	subsurface	83-08-20	DL
s4241	ID(B)C	1	surface	83-08-20	100
S4242	ID(B)C	1	subsurface	83-08-20	DL
S4243	ID(B)C	2	surface	83-08-20	11000
s4244	ID(B)C	2	subsurface	83-08-20	480
S4245	ID(B)C	3	surface	83-08-20	1600
s4246	ID(B)C	3	subsurface	83-08-20	78
S4247	ID(B)C	4	surface	83-08-20	260
s4248	ID(B)C	4	subsurface	83-08-20	88
S4249	ID(B)C	plot	surface	83-08-20	130
S4250	ID(B)C	plot	subsurface	83-08-20	DL
S4251	ID(B)E	1	surface	83-08-20	87
S4252	ID(B)E	1	subsurface	83-08-20	DL
S4253	ID(B)E	2	surface	83-08-20	5300
S4254	ID(B)E	2	subsurface	83-08-20	89
S4255	ID(B)E	3	surface	83-08-20	210
S4256	ID(B)E	3	subsurface	83-08-20	DL
S4257	ID(B)E	4	surface	83-08-20	1900
S4258	ID(B)E	4	subsurface	83-08-20	330
S4259	ID(B)E	plot	surface	83-08-20	170
s4260	ID(B)E	plot	subsurface	83-08-20	DL

Table A.3 (cont.)

SAMPLE NO.	PLOT	LOCATION		DATE	t -h (mg/kg)
S4201	ICC	1	surface	83-08-20	72
S4202	ICC	1	subsurface	83-08-20	28
S4203	ICC	2	surface	83-08-20	9100
S4204	ICC	2	subsurface	83-08-20	250
S4205	ICC	3	surface	83-08-20	130
S4206	ICC	3	subsurface	83-08-20	110
S4207	ICC	4	surface	83-08-20	210
S4208	ICC	4	subsurface	83-08-20	20
S4209	ICC	plot	surface	83-08-20	380
S4210	ICC	plot	subsurface	83-08-20	21
S4211	ICE	1	surface	83-08-20	30
S4212	ICE	1	subsurface	83-08-20	DL
S4213	ICE	2	surface	83-08-20	1300
S4214	ICE	2	subsurface	83-08-20	DL
S4215	ICE	3	surface	83-08-20	450
S4216	ICE	3	subsurface	83-08-20	160
S4217	ICE	4	surface	83-08-20	1400
S4218	ICE	4	subsurface	83-08-20	41
S4219	ICE	plot	surface	83-08-20	7800
S4220	ICE	plot	subsurface	83-08-20	440
S4221	ID(E)C	1	surface	83-08-20	87
S4222	ID(E)C	1	subsurface	83-08-20	DL
S4223	ID(E)C	2	surface	83-08-20	3100
s4224	ID(E)C	2	subsurface	83-08-20	350
S4225	ID(E)C	3	surface	83-08-20	160
s4226	ID(E)C	3	subsurface	83-08-20	22
S4227	ID(E)C	4	surface	83-08-20	69
S4228	ID(E)C	4	subsurface	83-08-20	DL
S4229	ID(E)C	plot	surface	83-08-20	170
S4230	ID(E)C	plot	subsurface	83-08-20	20

Additional samples (located on Figure 4.2, page 4-3)

S4281		1	surface	83-08-20	DL
S4282		1	subsurface	83-08-20	DL
S4283		2	surface	83-08-20	25
S4284		2	subsurface	83-08-20	DL
S4285		3	surface	83-08-20	21
s4286		3	subsurface	83-08-20	DL
S4287		4	surface	83-08-20	100
S4288		4	subsurface	83-08-20	DL
S4289		5	surface	83-08-20	53
S4290		5	subsurface	83-08-20	sample lost
S4291		6	surface	83-08-20	DL
S4292		6	subsurface	83-08-20	78

Table A.4 Results of Analyses from Samples Collected in 1983 from 1982 Backshore Experimental and Control Plots

SAMPLE NO.	PLOT	LOCATION		DATE	t-h (mg/kg)
S4261	IMC-C	Berm	surface	83-08-20	62000
S4262	IMC-C	Berm	subsurface	83-08-20	930
S4263	IMC-C	Back	surface	83-08-20	22000
S4264	IMC-C	Back	subsurface	83-08-20	48o
S4265	IMC-M	Berm	surface	83-08-20	31000
S4266	IMC-M	Berm	subsurface	83-08-20	2300
S4267	IMC-M	Back	surface	83-08-20	11000
S4268	IMC-M	Back	subsurface	83-08-20	4500
S4269	i-ME-C	Berm	surface	83-08-20	11000
S4270	IME-C	Berm	subsurface	83-08-20	7100
S4271	IME-C	Back	surface	83-08-20	14000
S4272	IME-C	Back	subsurface	83-08-20	280
S4273	IME-M	Berm	surface	83-08-20	7400
S4274	IME-M	Berm	subsurface	83-08-20	7800
S4275	IME-M	Back	surface	83-08-20	11000
S4276	IME-M	Back	subsurface	83-08-20	5500

Table A.5 Results of Analyses from Samples Collected in 1983 from the Beaches of Ragged Channel

SAMPLE No.	LOCATION	POSITION	DATE	t -h (mg/kg)
s4160	Bay 9 - profile 100	upper surface	83-08-10	DL
s4162	Bay 9 - profile 100	upper subsurface	83-08-10	DL
S4163	Bay 9 - profile 100	middle surface	83-08-10	DL
s4164	Bay 9 - profile 100	middle subsurface	83-08-10	DL
S4165	Bay 9 - profile 100	lower surface	83-08-10	DL
s4166	Bay 9 - profile 100	lower subsurface	83-08-10	DL
S4167	Bay 9 - profile 300	upper surface	83-08-10	DL
S4168	Bay 9 - profile 300	upper subsurface	83-08-10	DL
S4169	Bay 9 - profile 300	middle surface	83-08-13	DL
S4170	Bay 9 - profile 300	middle subsurface	83-08-13	DL
S4171	Bay 9 - profile 300	lower surface	83-08-13	DL
S4172	Bay 9 - profile 300	lower subsurface	83-08-10	DL
S4173	Bay 11 - profile 2	upper surface	83-08-16	910
S4174	Bay 11 - profile 2	upper subsurface	83-08-16	82
S4177	Bay 11 - profile 2	middle surface	83-08-16	830
s4178	Bay 11 - profile 2	middle subsurface	83-08-16	420
S4183	Bay 11 - profile 2	lower surface	83-08-16	110
.s4184	Bay 11 - profile 2	lower subsurface	83-08-16	43
s4185	Bay 11 - profile 4	upper surface	83-08-16	27000
S4186	Bay 11 - profile 4	upper subsurface	83-08-16	1500
s4189	Bay 11 - profile 4	middle surface	83-08-16	3100
S4190	Bay 11 - profile 4	middle subsurface	83-08-16	2300
S4195	Bay 11 - profile 4	lower surface	83-08-16	60
s4196	Bay 11 - profile 4	lower subsurface	83-08-16	29
S4197	Bay 11 - profile 6	upper surface	83-08-16	58000
S4198	Bay 11 - profile 6	upper subsurface	83-08-16	550
S4201	Bay 11 - profile 6	middle surface	83-08-16	14000
S4202	Bay 11 - profile 6	middle subsurface	83-08-16	1100
S4207	Bay 11 - profile 6	lower surface	83-08-16	2800
s4208	Bay 11 - profile 6	lower subsurface	83-08-16	1200
S4209	Bay 11 - profile 8	upper surface	83-08-16	3300
.S4210	Bay 11 - profile 8	upper subsurface	83-08-16	220
S4213	Bay 11 - profile 8	middle surface	83-08-16	1800
S4214	Bay 11 - profile 8	middle subsurface	83-08-16	7500
S4219	Bay 11 - profile 8	lower surface	83-08-16	1400
S4220	Bay 11 - profile 8	lower subsurface	83-08-16	470
Additional Samples				
S4301	Bay 11 - site 1	surface	83-08-21	27000
S4302	Bay 11 - site 1	subsurface	83-08-21	4600
S4303	Bay 11 - site 2	surface	83-08-21	470
S4304	Bay 11 - site 2	subsurface	83-08-21	DL
S4305	Bay 11 - site 3	surface	83-08-21	180
S4 306	Bay 11 - site 3	subsurface	83-08-21	DL
S4307	Bay 11 - site 4	surface	83-08-21	810
s4308	Bay 11 - site 4	subsurface	83-08-21	28
S4309	Bay 11 - site 5	surface	83-08-21	9700
S4310	Bay 11 - site 5	subsurface	83-08-21	5900
S4311 (*)	Bay 11 - site 6	surface	83-08-21	27000
S4312 (*)	Bay 11 - site 6	subsurface	83-08-21	1500

Table A.5 (cont.)

SAMPLE NO.	LOCATION	POSITION	DATE	t-h (mg/kg)
S4313	Bay 11 - site 7	surface	83-08-21	550
S4314	Bay 11 - site 7	subsurface	83-08-21	20
S4317	Bay 11 - site 9	surface	83-08-21	2800
s4318	Bay 11 - site 9	subsurface	83-08-21	490

* s4311 ❑ s4185

* S4312 ❑ s4186